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Hazardous Waste TSDF (Treatment, Storage, and Disposal Facilities) Fugitive Particulate Matter Air Emissions Guidance Document

Midwest Research Inst., Kansas City, MO

Prepared for:

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Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

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16. ABSTRACT

The purpose of this document is to provide regulatory and industrial personnel with sufficient information to identify sources of contaminated fugitive PM emissions, estimate the magnitude of emissions, select viable control measures, and estimate the effectiveness of those measures in order to ensure that high risks from these facilities do not occur. The following sources are discussed in this document: paved and unpaved roads, open waste piles and staging areas, dry surface impoundments, landfills, land treatment, and waste stabilization.

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HAZARDOUS WASTE TSDF FUGITIVE PARTICULATE MATTER AIR EMISSIONS GUIDANCE DOCUMENT

by

C. Cowherd, P. Englehart, G. E. Muleski, J. S. Kinsey
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

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William L. Elmore, Project Officer
Emission Standards Division

Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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Technical Contributors

Chat Cowherd, MRI
Dennis Doll, SRAB
Ken Durkee, ESD
Michael Dusetzina, PAB
Larry Elmore, ESD
Phil Englehart, MRI
John Kinsey, MRI
Greg Muleski, MRI

Word Processing Staff

Janice Evans, MRI
Kristy Henry, MRI
Cindy Melenson, MRI
Susie Powell, MRI

CONTENTS

Acknowledgments.................... iii
Figures.................... ix
Tables.................... xi

- 1.0 Introduction.................... 1-1
  - 1.1 Regulatory requirements for fugitive dust control under RCRA.................... 1-1
  - 1.2 Particulate emission factor models.................... 1-4
  - 1.3 Preventive and mitigative control options.................... 1-7
  - 1.4 On-site versus off-site facilities.................... 1-9
  - 1.5 Organization of this document.................... 1-10
  - 1.6 References for Section 1.................... 1-10
- 2.0 Paved and Unpaved Roads.................... 2-1
  - 2.1 Paved roads.................... 2-2
    - 2.1.1 Source description.................... 2-2
    - 2.1.2 Estimation of uncontrolled emissions.................... 2-4
    - 2.1.3 Demonstrated control techniques.................... 2-7
    - 2.1.4 Control performance estimation/specification.................... 2-11
    - 2.1.5 Procedures for compliance determination.................... 2-20
  - 2.2 Unpaved roads.................... 2-24
    - 2.2.1 Source description.................... 2-24
    - 2.2.2 Estimation of uncontrolled emissions.................... 2-26
    - 2.2.3 Demonstrated control techniques.................... 2-29
    - 2.2.4 Control performance estimation.................... 2-34
    - 2.2.5 Procedures for compliance determination.................... 2-47
  - 2.3 Example calculation.................... 2-51
    - 2.3.1 Paved road estimates.................... 2-53
    - 2.3.2 Unpaved road estimates.................... 2-55
  - 2.4 References for Section 2.................... 2-57
- 3.0 Open Waste Piles and Staging Areas.................... 3-1
  - 3.1 Source description.................... 3-1
  - 3.2 Estimation of uncontrolled emissions.................... 3-2
    - 3.2.1 Materials handling.................... 3-5
    - 3.2.2 Wind erosion.................... 3-6
    - 3.2.3 Wind erosion of continuously active piles.................... 3-19
    - 3.2.4 Level of contamination.................... 3-20
  - 3.3 Demonstrated control techniques.................... 3-21
  - 3.4 Control performance estimation.................... 3-22
    - 3.4.1 Chemical stabilization.................... 3-23
    - 3.4.2 Enclosures.................... 3-24
    - 3.4.3 Wet suppression systems.................... 3-29

CONTENTS (continued)

3.5 Procedures for compliance determination........... 3-39
3.6 Example calculation.............................. 3-39
3.7 References for Section 3......................... 3-47

4.0 Dry Surface Impoundments.............................. 4-1
4.1 Source description.............................. 4-1
4.2 Estimation of uncontrolled emissions.............. 4-3
4.2.1 Wind erosion............................. 4-3
4.2.2 Removal of surface material.................. 4-16
4.2.3 Level of contamination........................ 4-18
4.3 Demonstrated control techniques..................... 4-18
4.4 Control performance estimation...................... 4-20
4.4.1 Physical stabilization.................... 4-21
4.4.2 Chemical stabilization..................... 4-21
4.4.3 Wind fences/barriers....................... 4-22
4.4.4 Watering of unpaved surfaces.................. 4-28
4.4.5 Wet suppression for materials handling..... 4-33
4.5 Procedures for compliance determination........... 4-38
4.6 Example calculation.............................. 4-39
4.7 References for Section 4......................... 4-40

5.0 Landfills.. 5-1
5.1 Source description.............................. 5-1
5.2 Estimation of uncontrolled emissions.............. 5-6
5.2.1 Particulate emission rates................ 5-6
5.2.2 Level of contamination...................... 5-12
5.3 Control techniques.............................. 5-12
5.3.1 Preventive controls....................... 5-14
5.3.2 Mitigative controls....................... 5-15
5.4 Control performance estimation..................... 5-17
5.5 Procedures for compliance determination........... 5-18
5.5.1 Preventive controls....................... 5-18
5.5.2 Mitigative controls....................... 5-21
5.6 Example calculation.............................. 5-22
5.7 References for Section 5......................... 5-27

6.0 Land Treatment.. 6-1
6.1 Source description.............................. 6-1
6.2 Estimation of uncontrolled emissions.............. 6-4
6.2.1 Particulate emission rates................ 6-4
6.2.2 Level of contamination (a).................... 6-7
6.3 Control techniques.............................. 6-7
6.3.1 Preventive controls....................... 6-9
6.3.2 Mitigative controls....................... 6-10
6.4 Control performance estimation..................... 6-10
6.5 Procedures for compliance determination........... 6-11
6.5.1 Preventive controls....................... 6-14
6.5.2 Mitigative controls....................... 6-16
6.6 Example calculation.............................. 6-17
6.7 References for Section 6......................... 6-18

CONTENTS (continued)

7.0 Waste Stabilization.................................... 7-1
  7.1 Source description.................................... 7-1
    7.1.1 Site characteristics.................................... 7-1
    7.1.2 Emission sources.................................... 7-5
  7.2 Estimation of uncontrolled emissions.................................... 7-7
    7.2.1 Particulate emission rates.................................... 7-7
    7.2.2 Level of contamination (α).................................... 7-11
  7.3 Control techniques.................................... 7-12
    7.3.1 Preventive controls.................................... 7-13
    7.3.2 Mitigative controls.................................... 7-15
  7.4 Control performance estimation.................................... 7-17
    7.4.1 Wind fences or barriers.................................... 7-17
    7.4.2 Capture/collection systems.................................... 7-19
    7.4.3 Wet suppression.................................... 7-23
    7.4.4 Watering of unpaved surfaces.................................... 7-24
    7.4.5 Paved surface cleaning.................................... 7-28
  7.5 Procedures for compliance determination.................................... 7-30
    7.5.1 Permit systems.................................... 7-30
    7.5.2 Indirect measures of control performance... 7-37
  7.6 Example calculation.................................... 7-38
    7.6.1 Process description.................................... 7-38
    7.6.2 Raw material handling.................................... 7-39
    7.6.3 Vehicle traffic on unpaved surfaces.................................... 7-40
  7.7 References for Section 7.................................... 7-42

Appendices

A. Open dust source emission factor rating and control efficiency terminology.................................... A-1
B. Estimation of control costs and cost effectiveness...... B-1
C. Screening techniques, modeling information, and health risks information.................................... C-1
D. Sampling and analysis procedures.................................... D-1

FIGURES

Number Page

2-1 Traffic count log.. 2-22
2-2 Sampling data form for paved roads.................................... 2-23
2-3 Mean annual number of days with at least 0.01 in of precipitation.. 2-28
2-4 Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).. 2-38
2-5 Watering control effectiveness for unpaved travel surfaces... 2-39
2-6 Average PM_{10} control efficiency for chemical suppressants.. 2-42
2-7 Example chemical suppressant application log.................. 2-49
2-8 Example completed log.. 2-50
2-9 Roads at a hypothetical TSDF.. 2-52
3-1 Open waste piles and staging areas.................................. 3-4
3-2 Illustration of logarithmic velocity profile........................ 3-8
3-3 Relationship of threshold friction velocity to size distribution mode.. 3-13
3-4 Scale of threshold friction velocities................................. 3-14
3-5 Contours of normalized surface wind speeds, u_s/u_r.......... 3-16
3-6 Decay in control efficiency of latex binder applied to coal storage piles.. 3-23
3-7 Example. Pile surface areas within each wind speed regime.. 3-41
3-8 Daily fastest miles of wind for periods of interest............. 3-42
3-9 Field procedure for determination of threshold friction velocity.. 3-43
4-1 Surface impoundment activities....................................... 4-2
4-2 Illustration of logarithmic velocity profile........................ 4-6
4-3 Roughness heights for various surfaces.............................. 4-7
4-4 Relationship of threshold friction velocity to size distribution mode.. 4-9
4-5 Field procedure for determination of threshold friction velocity.. 4-10
4-6 Increase in threshold friction velocity with L_c................ 4-12
4-7 Scale of threshold friction velocities................................. 4-14
4-8 Decay in control efficiency of latex binder applied to coal storage piles.. 4-22
4-9 Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).. 4-30
4-10 Watering control efficiency effectiveness for scraper travel on unpaved surfaces... 4-31

FIGURES (continued)

Number Page

4-11 Typical form for recording watering program control parameters.. 4-34
5-1 Line drawings of common equipment types at HW landfills.... 5-3
5-2 (a) Hypothetical landfill unit plan view; (b) profile view; (c) hypothetical landfill with master cell/subcell configuration.. 5-4
6-1 Land treatment units--physical configurations............. 6-3
6-2 Flowchart for evaluating control associated with waste application... 6-12
6-3 Procedure for estimating control efficiency with O&G content and moisture content measurements................. 6-13
7-1 General pozzolanic process flow diagram...................... 7-6
7-2 Mean annual number of days with at least 0.01 in of precipitation... 7-10
7-3 Performance evaluation of capture/collection systems....... 7-22
7-4 Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).. 7-26
7-5 PM_{10} control efficiency for watering unpaved surfaces...... 7-27
7-6 Typical form for recording watering program control parameters.. 7-35

TABLES

Number Page

2-1 Possible default values for paved road emission estimates at TSDFs.. 2-5
2-2 Selection of paved road emission factor.................. 2-6
2-3 Measured efficiency values for paved road controls......... 2-8
2-4 Outline of preventive paved road control measures applicable to TSDFs... 2-9
2-5 Miscellaneous operation/design and cost data for vacuum sweeping paved roads.. 2-15
2-6 Miscellaneous operation/design and cost data for flushing/broom sweeping paved roads........................ 2-19
2-7 Possible default values for unpaved road estimates at TSDFs.. 2-28
2-8 Control techniques for unpaved travel surfaces............. 2-31
2-9 Chemical stabilizers.. 2-32
2-10 Summary of unpaved road chemical dust suppressant costs.... 2-46
2-11 Recordkeeping requirements for unpaved road controls....... 2-48
2-12 Summary information for roads A, B, and C................. 2-53
3-1 Typical silt and moisture content values of materials at various industries.. 3-3
3-2 Erosion potential function....................................... 3-11
3-3 Threshold friction velocities--industrial aggregates....... 3-12
3-4 Threshold friction velocities--Arizona sites............... 3-12
3-5 Subarea distribution for regimes of u_s/u_r................. 3-17
3-6 Control techniques for storage piles........................ 3-22
3-7 Capital and O&M items for chemical stabilization of waste piles.. 3-25
3-8 Typical form for recording chemical dust suppressant control parameters.. 3-26
3-9 Typical form for recording delivery of chemical dust suppressants... 3-27
3-10 Summary of available control efficiency data for water sprays... 3-32
3-11 Summary of available control efficiency data for foam suppression systems... 3-33
3-12 Wet suppression system capital and O&M cost elements....... 3-36
3-13 Typical costs for wet suppression of material transfer points... 3-37
3-14 Compliance determination for waste piles.................. 3-40
3-15 Example calculation of uncontrolled PM_{10} emissions......... 3-45
3-16 Example calculation of controlled PM_{10} emissions........... 3-47

TABLES (continued)

Number Page

4-1 Threshold friction velocities.................................. 4-13
4-2 Threshold friction velocities--Arizona sites.............. 4-13
4-3 Control techniques for dry surface impoundments............ 4-20
4-4 Capital and O&M items for chemical stabilization of open area sources.. 4-23
4-5 Typical form for recording chemical dust suppressant control parameters... 4-24
4-6 Typical form for recording delivery of chemical dust suppressants.. 4-25
4-7 Wet suppression system capital and O&M cost elements....... 4-37
4-8 Compliance determination for dry surface impoundments...... 4-39
5-1 Emission factors for hazardous waste landfill unit operations... 5-8
5-2 Emission factor correction terms and source extents for sampled landfill units... 5-9
5-3 Mean wind speed [U] for selected United States stations.... 5-10
5-4 Summary of RCRA metals concentration (μg/g)................. 5-13
5-5 Example observation/audit checklist for landfill preventive control practices.................................. 5-19
6-1 Model plant size distributions for land treatment units.... 6-2
6-2 Summary of RCRA metals concentrations (μg/g) for land treatment units handling refinery wastes.................. 6-8
6-3 Example observation/audit checklist for land treatment preventive control practices.................................. 6-15
7-1 PM-10 emission factors and correction parameters for waste stabilization.. 7-9
7-2 Summary of RCRA metals concentration for waste stabilization samples... 7-13
7-3 Measured efficiency values for paved surface controls...... 7-29

1.0 INTRODUCTION

Earlier EPA studies that evaluated fugitive particulate matter (PM) emissions from hazardous waste Treatment, Storage, and Disposal Facilities (TSDFs) indicated that risks from contaminated PM emissions from these facilities are potentially significant. Sources of particular concern are landfills, land treatment, waste stabilization, dry surface impoundments, and roads. These sources of emissions are regulated by a site-specific permitting system for TSDFs that has been established under the authority of the Resource Conservation and Recovery Act (RCRA).

The purpose of this document is to provide regulatory and industrial personnel with sufficient information to identify sources of contaminated fugitive PM emissions, estimate the magnitude of emissions, select viable control measures, and estimate the effectiveness of those measures in order to ensure that high risks from these facilities do not occur. The PM particle size fraction of interest, designated as PM_{10}, consists of particles with an aerodynamic diameter equal to or less than 10 micrometers (μm).

The remainder of this introduction addresses some of the general issues associated with TSDF PM emissions and their control. Separate subsections discuss the regulatory basis for fugitive PM control at TSDFs, the procedures used to estimate fugitive PM emissions, fugitive PM control strategies, and potential differences in on-site and commercial TSDFs. The final subsection outlines the organization of the remaining sections of the document.

1.1 REGULATORY REQUIREMENTS FOR FUGITIVE DUST CONTROL UNDER RCRA

Regulations developed under the authority of the RCRA provide for control of hazardous waste (TSDF) releases that are potentially harmful to human health and the environment. Contaminated fugitive (PM) emissions are by definition included in those releases controlled under

RCRA. Generally, this regulatory control is accomplished via a two-step process. The interim and final status regulations promulgated in 40 CFR Parts 264 and 265 provide general performance requirements for TSDFs. However, the primary focus under RCRA is the facility-specific permit requirements issued as a part of the Part B (or final status) permit that is issued under 40 CFR Part 270. Permit writers generally have wide latitude in defining the permit conditions that are needed to meet the Part 264 performance requirements, and effective control of fugitive PM emissions depends upon these facility-specific requirements.

Contaminated fugitive PM emissions from land-based TSDFs are addressed in three places--the general facilities standards, the facility-specific regulations, and the permit provisions. The omnibus provisions in the general facilities standards of Part 264 generally prohibit any releases to the environment that are harmful to human health or the environment. Specific provisions that apply to fugitive PM emissions include the following:

1. 40 CFR 264.15 requires that owners/operators inspect facilities for malfunctions, deterioration, operating errors, and discharges which cause or lead to discharge of hazardous constituents to the environment.
2. 40 CFR 264.31 requires that facilities be designed, constructed, maintained, and operated to minimize unplanned sudden or nonsudden release of hazardous constituents to the environment (including atmospheric releases).
3. 40 CFR 264.11 requires that owners/operators close facilities in a manner that minimizes or eliminates, to the extent necessary to protect the human health and environment, the release of hazardous constituents.

The facility-specific regulations in Part 264 address wind dispersal of dust. The regulations for waste piles (40 CFR Parts 264.251[f] and 264.254[b]), land treatment (40 CFR Parts 264.273[f] and [g]), and landfills (40 CFR Parts 264.301[f] and 264.303[b]) specifically address windblown dust. They require that the owner/operator cover or otherwise manage the facility to control windblown dust. In addition, the owner/operator must inspect the wind dispersal control system weekly. Relative to closure of surface impoundments, the process-specific regulations (40 CFR 264.228) require that the owner/operator either remove contaminated liners and subsoils from the facility or cover them with a final cover that minimizes erosion and abrasion.

The permit requirements of Part 270 also address fugitive dust. The regulations require that for waste piles (40 CFR Part 270.18[c][5]), landfills (40 CFR Part 270.21[b][5]), and land treatment facilities (40 CFR Part 270.20[c][6]), owners/operators provide detailed plans or engineering descriptions of methods to control windblown particulate matter in their Part B application.

The regulations described above require that dust emissions be controlled and that plans be provided for control of those emissions. They do not establish specific emissions limits or control technology requirements. These specific requirements are established in the RCRA Part B permitting process. General EPA policy relative to specific requirements often is presented in permit guidance materials.

According to the "Permit Applicants' Guidance Manual"[1] prepared by the Office of Solid Waste (OSW), Part B permit applications for land-based TSDFs should include, as an attachment, a "Wind Dispersal Flow Control Plan." The plan should contain (a) a description of methods for controlling wind dispersal and (b) data to estimate the effectiveness of control techniques. The discussion of the types of techniques that could be used is brief and general in nature (e.g., suggestion of watering or windbreaks). No specific design or operating requirements are provided.

Thus the overall objective of this document is to provide detailed information on applicable control techniques, methods of determining control technique effectiveness, possible methods of ensuring compliance, and general cost information to regulatory agency personnel plus owners and operators of TSDFs. This information should assist the TSDF permit writer in determining whether the Wind Dispersal Flow Control Plan submitted by a TSDF owner/operator is adequate, given site-specific factors. Also, this information should assist TSDF owners and operators in developing a Wind Dispersal Flow Control Plan.

1.2 PARTICULATE EMISSION FACTOR MODELS

In developing particulate control strategies for "traditional" pollutant concerns (i.e., to meet National Ambient Air Quality Standards [NAAQS]), gross particulate emissions from open sources are estimated using the predictive emission factors presented in Section 11.2 of EPA's "Compilation of Air Pollutant Emission Factors" (AP-42).[2] These factors cover the generic source categories:

- Unpaved travel surfaces
- Paved travel surfaces
- Exposed areas (wind erosion)
- Materials handling

Note that these factors are updated periodically and that users of this document should use updated factors as they become available. All factors cited in the document represent the most current versions as of September 1988 (Reference 2).

These emission factors share many common features. For example, the models are formulated as empirical expressions that relate variations in emission factor (e) to differences in the physical properties (p) of the material being disturbed and the mechanical energy (m) responsible for the generation of particulate according to the general form:

$$e = Kp^a m^b \tag{1-1}$$

As empirical models, open dust source factors have adjustable coefficients (K,a,b) that reflect relationships determined from actual open dust source testing.

As indicated in Section 1.1, much of this guidance document centers on the application of the open dust factors to estimate particulate emissions from permitted TSDF units.

Estimation is accomplished according to the general model form:

$$R = \sum_{j=1}^{n} \alpha_j \cdot e_j \cdot A_j \qquad (1\text{-}2)$$

where: R = emission rate of contaminated airborne particulate (kg/yr) for a given TSDF, consisting of n identifiable unit operations

α_j = fraction of contaminant in particulate emissions for the jth operation (μg/g); for uncontaminated particulate emissions, $\alpha_j = 0$

e_j = emission factor(s) (mass/source extent)

A_j = source extent(s) (source dependent units)

This approach is analogous to that used by MRI in recent work on estimation of emissions from surface contamination sites.[3] The approach is also consistent with techniques used in air pollution assessments.

In the TSDF context it is important to recognize the following:

1. The α term refers to the "level of contamination" and is usually represented as the concentration (e.g., μg/g) of the metal(s) or organic compound(s) of concern in the disturbed material.
2. Permitted TSDF units may consist of multiple, identifiable unit operations; in the case of landfills, for example, unit operations include loadout of bulk hazardous waste, loadout of temporary cover, lift construction, and general vehicle traffic proximate to the landfill face.
3. The major assumption implicit in Eq. 1-2 is that TSDF processes that generate particulate emissions can be adequately represented by existing open dust source emission factor models.

Item 2 above is relatively straightforward and is demonstrated in the individual chapters. Items 1 and 3 require further clarification as given below.

Specification of the level of contamination (α) probably is the single most difficult aspect of applying the emission factors. For a given TSDF source, "representative" value(s) of α may depend upon a number of factors including principally:

1. The nature of waste streams handled and whether the wastes are metal-containing or organic waste streams.
2. Operational practices that influence the availability of waste material for entrainment into the atmosphere.
3. The age of the facility to the extent that it reflects "residual" contamination associated with long-term disposal and typical waste stream volumes.

Note that the term *representative* is used here to connote a long-term value, such as an annual mean, that adequately defines α over the entire TSDF source.

There are essentially two methods for specification of α. The preferred method is through source-specific sampling and analysis (S&A). Appendix D outlines generic elements of a source-specific program for characterization of both physical and chemical (i.e., α) properties of surface materials at TSDFs. In some cases it may be feasible to develop estimates of α for a specific source based on existing information other than actual S&A data. In general, these estimates should be developed from the perspective of a "worst-case scenario," because of the greater uncertainty involved. In other words, they should be conservatively high and thus tend to protect against any potential underestimation of risk associated with particulate emissions.

The principal sources of information for worst-case estimates are expected to be:

1. Waste manifests and any "tracking" information that a facility routinely generates to characterize its receipts.
2. Conversations with facility personnel.

Because the emission factor models are empirical expressions, in a strict sense their degree of applicability relative to TSDF sources is related to the degree of compliance with two conditions:

1. How closely a given TSDF unit operation resembles the source conditions underlying test data used in development of the emission factor.

2. How closely the physical characteristics of the disturbed material resemble those tested in development of the emission factor.

Based on surveys described in reference 4, the general conclusion is that TSDF unit operations are reasonably comparable to those tested in development of the emission factor relationships. Of course, this agreement varies from source to source. For example, the emission factor for vehicle traffic on unpaved roads encompasses most common traffic conditions--vehicle types, operating speeds, and weights--found at TSDFs. On the other hand, the emission factor applied to one of the important unit operations at landfills--lift construction--is based on source testing that does not bear strong resemblance to TSDF operations.

Results of the surveys described in reference 3 also clearly point out that the physical characteristics of waste and disturbed surface materials at TSDFs do not always conform closely to those materials tested in development of the emission factors. More specifically, the moisture and/or "oily nature" of waste streams may be markedly different from the dry, finely divided materials upon which the field tests were performed. The current emission factor models do not fully account for the inherent mitigation provided by the physical binding effect of oily substances, which may add conservatism to the predictive emission rates. However, at any given facility, the potential for increased spreading of material may offset this conservatism.

1.3 PREVENTIVE AND MITIGATIVE CONTROL OPTIONS

Typically, there are several options for control of fugitive particulate emissions from any given source. This is clear from the mathematical equation used to calculate the emissions rate:

$$R = A\,e\,(1 - c) \qquad (1\text{-}3)$$

where: R = estimated mass emission rate

A = source extent (i.e., surface area for most open dust sources) e = uncontrolled emission factor, i.e., mass of uncontrolled emissions per unit of source extent

c = fractional efficiency of control

To begin with, because the uncontrolled emission rate is the product of the source extent and uncontrolled emission factor, a reduction in either of these two variables produces a proportional reduction in the uncontrolled emission rate.

Although the reduction of source extent results in a highly predictable reduction in the uncontrolled emission rate, such an approach in effect usually requires a change in the process operation. Frequently, reduction in the extent of one source may necessitate the increase in the extent of another, as in the shifting of vehicle traffic from an unpaved road to a paved road.

The reduction in the uncontrolled emission factor may be achieved by process modifications (in the case of process sources) or by adjusted work practices (in the case of open sources). The degree of the possible reduction of the uncontrolled emission factor can be estimated from the known dependence of the factor on source conditions that are subject to alteration. For open dust sources, this information is embodied in the predictive emission factor equations for fugitive dust sources as presented in Section 11.2 of EPA's "Compilation of Air Pollutant Emission Factors" (AP-42).

Control techniques can be divided into two broad categories--preventive and mitigative. Although differences between the two are not always clear, in general, preventive measures involve techniques that reduce source extent or improve mechanical source operations relative to the generation of particulate emissions. By contrast, mitigative techniques typically focus on altering the surface/material conditions that constitute the source of particulate emissions.

In the TSDF context an example of a preventive control technique involves traffic routing of haul truck vehicles in the staging areas proximate to an active landfill face. The objective of traffic routing is to minimize the contact between vehicle wheels and waste material and thus limit the potential spreading of contamination material to the facility roadways. In this fashion the source extent of contaminated material is effectively reduced.

An example of a mitigative measure involves the application of water to unpaved travel surfaces in order to suppress the entrainment of gross or contaminated particulate by vehicle traffic. The important point here is that relative to contaminated particulate, it is assumed that the roadways are characterized by some (albeit unknown) level of contamination (α) associated with long-term waste disposal operations, and that the objective is to minimize the entrainment of this material into the atmosphere.

1.4 ON-SITE VERSUS OFF-SITE FACILITIES

Land-based hazardous waste TSDFs generally are classified as on-site facilities, i.e., those facilities that generate and treat or dispose of waste streams on-site, versus off-site facilities--those that accept wastes from a variety of generators for treatment, storage, and disposal. According to recently released information,[5] 165 on-site facilities have received Part B permits; there are approximately 30 facilities with Part B permits still pending. According to the available information 35 off-site facilities have applied for Part B status, 22 facilities have received a permit; and 6 facilities have been ordered to close.

Relative to this document, the distinction between on-site and off-site facilities would appear to have several important implications. For example, as a general rule, one might expect on-site facilities to handle a more limited range of waste streams than off-site facilities. Similarly, it is reasonable to expect that on-site facilities will have more complete knowledge of waste stream composition. Thus, in the absence of detailed sampling and analysis (S&A) programs, specification of α for the calculation scheme (e.g., Eq. 1-2) may prove easier for on-site facilities than for off-site ones.

In evaluating particulate emissions from on-site facilities, one of the most difficult problems may be in separating that portion of the total facility associated with RCRA-related activities from the remainder of the facility which presumably is not subject to regulation under RCRA. Undoubtedly, this makes the evaluation very site-specific.

1.5 ORGANIZATION OF THIS DOCUMENT

Each section of this guidance document focuses on a different source category:

Section 2.0--Paved and Unpaved Roads
Section 3.0--Open Waste Piles and Staging Areas
Section 4.0--Dry Surface Impoundments
Section 5.0--Landfills
Section 6.0--Land Treatment
Section 7.0--Waste Stabilization

Each section begins with an overview of the source category, describing emission characteristics and mechanisms. Following this, available emission factors are presented to provide a basis for analyzing the operative nature of control measures. Next, demonstrated control techniques are discussed in terms of estimating efficiency and determining costs of implementation. Suggested regulatory formats explain the "philosophy" used in implementing the preceding technical discussions in viable regulations and compliance actions.

In addition, a series of appendices are included. These provide information on (a) terminology used in this manual, (b) a general costing procedure used for open dust source controls, (c) screening atmospheric modeling techniques and health risk information, and (d) generic methods for sampling and analysis of material samples from TSDFs.

1.6 REFERENCES FOR SECTION 1

1. U.S. Environmental Protection Agency. Permit Applicants' Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities. Final Draft, EPA 530 SW-84-004, Washington, D.C. May 1984.

2. U.S. Environmental Protection Agency. Compilation of Air Pollution Emission Factors (AP-42), Fourth Edition, September 1985; Supplement A, October 1986; Supplement B, September 1988. Research Triangle Park, North Carolina. September 1988.

3. Cowherd, C., G. E. Muleski, P. J. Englehart, and D. A. Gillette. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites. EPA/600-8-85/002, prepared for U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C. February 1985.

4. Englehart, P., and D. Wallace. Assessment of Hazardous Waste TSDF Particulate Emissions. Final Report, EPA Contract No. 68-02-3891, Work Assignment Nos. 5 and 13. October 1986.

5. Business Publishers, Inc. "Hazardous Waste News," Vol. 10, No. 49. p. 42. December 12, 1988.

2.0 PAVED AND UNPAVED ROADS

Unlike the sources described in other sections of this manual, the emissions from paved and unpaved roads at hazardous waste (HW) treatment, storage, and disposal facilities (TSDFs) are not due to an identifiable unit operation at each facility. Rather, the roads serve as "linkages" between the various unit operations (e.g., access from the gate to the active disposal area, transfer of solidified wastes from the solidification unit to a disposal unit, etc.). Consequently, the approach taken in this section will be somewhat unique in that the emission sources will be discussed in very general terms and not in the context of a specific TSDF unit operation.

Particulate emissions occur whenever a vehicle travels over a paved or unpaved surface, such as a road or an area proximate to a TSDF unit operation. Note that travel areas adjacent to TSDF operations may have a high potential for contaminated particulate emissions, with the potential inversely related to the level of "good operating practices" at the unit operation. In the case of paved roads, emissions originate with (a) resuspension from vehicle tires and undercarriages or (b) material deposited onto the surface. Material tracked onto the road from potentially contaminated travel areas surrounding TSDF operations will be spread along the road's length and eventually some of that material will become airborne. While track-on of material is usually more noticeable on paved roads, the spreading of potentially contaminated material also occurs on unpaved surfaces.

Past surveys of TSDFs have in fact indicated that unpaved road surfaces at these types of facilities may have RCRA metal and semivolatile organic contamination levels essentially comparable to levels in samples taken from process-related surfaces (e.g., landfill areas, areas surrounding a stabilization/solidification unit, etc.).[1] Because of the large volume of traffic associated with many facilities, those surveys suggest that general vehicular traffic on plant roads may be the principal source of contaminated emissions associated with TSDFs. While the source of road surface contamination cannot be definitively identified, the two most likely causes are (a) spillage from vehicles hauling the waste or (b) "track-out" of material from surfaces surrounding process operations at the TSDF.

In many respects, control measures commonly applied to alleviate "gross" (i.e., uncontaminated) particulate emissions may actually compound contaminated emissions. For example, travel areas surrounding an active TSDF unit operation may be watered to control emissions. However, watering tends to increase the amount of track-out onto an adjacent paved road, and the deposited material soon dries out and becomes airborne under normal plant traffic conditions.

2.1 PAVED ROADS

2.1.1 Source Description

Particulate emissions occur whenever a vehicle travels over a paved surface such as public and industrial roads and parking lots. These emissions may originate from materials previously deposited on the travel surface or from the resuspension of material from tires and undercarriages. In general, emissions are due to the surface material loading (measured as mass per unit area of the travel lanes) and that loading is continuously replenished by other sources (e.g., spillage, pavement wear, carryout from adjacent areas, etc.). Because of the importance of surface loading, available control techniques either attempt to prevent material from being deposited on the surface or to remove any material that has been deposited onto the travel lanes.[2]

2.1.1.1 Public vs. Industrial Roads. Although publicly owned roads are not common in HW TSDFs, transport to commercial facilities will almost always entail some travel on public roads. Thus, public roads may also be subject (although to a lesser degree than in-plant roads) to carry-out of possibly contaminated material from the TSDF. Should contaminated material reach the publicly owned system of roads, substantial increases in metals or organics emissions might be expected because all traffic (and not just that related to the TSDF) will cause resuspension.

2.1.1.2 Site Characteristics. While the mechanisms of material deposition and particulate resuspension are largely the same for public and industrial paved roads, there are often major differences in surface loading characteristics, emission levels, traffic characteristics, and viable control options.[3] For the purposes of estimating both gross and contaminated particulate emissions and developing control programs, the distinction between public and industrial roads is not so much a question of ownership/maintenance as one of surface loading and traffic characteristics. Decisions of this sort are discussed in Section 2.1.2 of this report.

2.1.1.3 Dust Emitting Activities. Although loose material on roadways and parking lots may become entrained from activities other than vehicular traffic (erosion during high wind events, for example), the principal long-term source of emissions for *active* roads and parking lots is undoubtedly vehicle travel. Vehicle-related activities are the only dust emitting activities considered in the rest of this chapter.

2.1.1.4 Potential Contamination Problems. As mentioned in the introduction to this chapter, significant contaminated air emissions from paved travel surfaces may occur if the surface loading contains measurable fractions of RCRA metals or organic compounds. Contaminants in the loose surface material on the roadway may be due to spillage during transport of HW or track-on of material which has become contaminated because of the various unit operations at the facility. Both sources may be at least partially controlled by instituting better operating practices at the facility. Again (as discussed in this section's introduction), it is important to note that control measures designed to reduce emissions at a unit operation may actually compound contaminated emissions on adjacent roadways.

2.1.2 Estimation of Uncontrolled Emissions

2.1.2.1 Particulate Emissions. Estimation of the total uncontrolled particulate emission rate R from paved TSDF roadways follows the general emission model presented earlier as Eq. 1-2.

$$R = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} e_i A_i \qquad (2\text{-}1)$$

where:

R_i = emission rate associated with the i-th road segment

e_i = emission factor applicable for the i-th road segment

A_i = source extent, in terms of vehicle distance traveled on road segment i over the averaging time of interest

n = number of road segments

Note that the estimation process described above makes use of "road segments," which are most easily defined as stretches of roads between intersections (i.e., connections to other road segments).

In general, the majority of traffic in a TSDF will be restricted to a relatively small number of roads within the facility. It is important, however, that all possible travel routes be considered.

EPA's "Compilation of Air Pollutant Emission Factors" (AP-42) indicates that the PM_{10} (particulate matter no greater than 10 µm in aerodynamic diameter) emission factor for paved roads may be written in the general form[3]

$$e_i = a(sL/b)^c \qquad (2\text{-}2)$$

where a, b, and c are constants and:

e_i = PM_{10} emission factor, in units of mass/vehicle/length

s = surface silt content, fraction of material smaller than 75 µm in diameter

L = total surface dust loading, mass/length^2

The product sL represents the mass of silt-size dust particles per unit area of the road surface and is usually termed the "silt loading." As is the case for all predictive models, *the use of site-specific values of sL is strongly recommended*. Recognizing that this is not always feasible, a summary of measured values is given as Table 2-1.

TABLE 2-1. POSSIBLE DEFAULT VALUES FOR PAVED ROAD EMISSION ESTIMATES AT TSDFs

Parameter (units)	Probable range	Possible default
Silt loading (g/m²)	0.3-30[a]	5[a,b]
Vehicle weight (Mg)		
--General plant vehicles	2-9	3[b]
--Commercial haulers	9-45	20[b]
--Plant haul trucks and equipment	20-50	30[b]

[a] Based on measurements taken from paved plant and adjacent public roads for 5 HW and municipal solid waste (MSW) landfills.

[b] As noted in text, use of site-specific data is *strongly* recommended.

The appropriate emission factor model (i.e., the constants a, b, and c) for a road segment depends upon:

- The mass of loose aggregate material less than 200 mesh per unit area of a paved road surface.
- The average weight of vehicles traveling on the road.

Selection of the appropriate emission factor is summarized in Table 2-2. An example problem illustrating the use of emission factor models is given in Section 2.3.

TABLE 2-2. SELECTION OF PAVED ROAD EMISSION FACTOR

Silt loading (sL)		Range weight (W)		Applicable PM_{10} emission factor	
g/m^2	oz/yd^2	Mg	Ton	g/VKT[a]	lb/VMT[a]
$sL < 2$	< 0.06	$W > 4$	> 4.4	$220\ (sL/12)^{0.3}$[b]	$0.78\ (sL/0.35)^{0.3}$[b]
$sL < 2$	< 0.06	$W < 4$	< 4.4	$2.28\ (sL/0.5)^{0.8}$[c]	$0.0081\ (sL/0.015)^{0.8}$[c]
$sL > 2$[d]	> 0.06	$W > 6$	> 6.6	$220\ (sL/12)^{0.3}$[b]	$0.78\ (sL/0.35)^{0.3}$[b]
$2 < sL < 15$	$0.06 < sL < 0.44$	$W < 6$	< 6.6	$220\ (sL/12)^{0.3}$[b]	$0.78\ (sL/0.35)^{0.3}$[b]
$sL > 15$[d]	> 0.44	$W < 6$	< 6.6	93	0.33

[a] VKT = Vehicle kilometers traveled, VMT = vehicle miles traveled.

[b] Commonly referred to as the "industrial" paved road model.[3]

[c] Commonly referred to as the "urban" paved road model.[3]

[d] For heavily loaded surfaces (i.e., $sL > \sim 300$ to $400\ g/m^2$ (9 to $12\ oz/yd^2$), it is recommended that the resulting estimate be compared to that from the unpaved road models (Section 2.2 of this manual), and the smaller of the two values used.

2.1.2.2 Contaminated Emissions. The emission rate R_j of particulate contaminated with a compound j can be represented as

$$R_j = \sum_{i=1}^{n} R_{ij} = \sum_{i=1}^{n} \alpha_{ij} \quad e_i A_i \tag{2-3}$$

where terms are as defined earlier and:

R_{ij} = emission rate of contaminant j from road segment i

α_{ij} = the fraction of contaminant j in the particulate emissions from road segment i

Because road surface contamination may result from spillage and/or track-on of material from a wide variety of wastes and areas around unit operations, no general rule of thumb for an appropriate value of α_{ij} (such as conservatively assuming 50% of the highest waste stream transported over the road) should be applied. Consequently, it is *strongly recommended* that material sampling be undertaken at operating facilities, and that those samples be analyzed for compounds of concern.

Information on α_{ij} can be determined either by direct or surrogate measurement. *Direct* measurement of α_{ij} requires the determination of specific contaminants in roadway emission samples collected at the TSDF. A *surrogate* measure of α_{ij} is the fraction of contaminant j in the silt loading for road i. An *alternate surrogate* measure would treat α_{ij} as a constant, set equal to the average fraction of contaminant j in all available silt loading samples. In that event, Eq. 2-3 above simplifies considerably to the form

$$R_j = \overline{\alpha_j} R \qquad (2\text{-}4)$$

where terms are as defined in Eqs. 2-1 and 2-3 and:

$\overline{\alpha_j}$ = mean value of the α_{ij}'s

Determining α_{ij} by the alternate surrogate measurement technique will provide sufficient information to conduct an initial risk assessment for a TSDF. If the initial risk assessment indicates that fugitive PM emissions result in unacceptable risks, the TSDF owner/operator should conduct an approved fugitive PM emission monitoring program in order to directly measure α_{ij}.

2.1.3 Demonstrated Control Techniques

As mentioned earlier, because emissions are directly related to the amount of material present on the road surface, control techniques for paved roads either attempt to prevent material from being deposited onto the surface (preventive controls) or attempt to remove any deposited material (mitigative controls). Preventive and mitigative control measures are discussed separately below. Measurement-based control efficiency values for control methods are presented in Table 2-3. Note that all values presented refer to mitigative controls.

TABLE 2-3. ESTIMATED METHODS FOR AVERAGE EFFICIENCY VALUES FOR PAVED ROAD CONTROLS[a]

Control	Average efficiency, C (%)[b]	Comments
Vacuum sweeping	$C = \begin{cases} 34, & D \le 2 \\ 68/D, & D > 2 \end{cases}$	340 m^3/min (12,000 cfm) blower tested
Water flushing	$C = \begin{cases} 69-0.116\ V, & V \le 299 \\ 10{,}300/V, & V > 299 \end{cases}$	Water applied at 2.2 L/m^2 (0.48 gal/yd^2)
Water flushing followed by broom sweeping	$C = \begin{cases} 96-0.132\ V, & V \le 365 \\ 17{,}500/V, & V > 365 \end{cases}$	Water applied at 2.2 L/m^2 (0.48 gal/yd^2)

[a] Based on PM-15 field emission measurements as given in Reference 2. PM-10 efficiency may be assumed equal to that for PM-15.

[b] In the expressions, D and V represent the number of days or vehicle passes, respectively, since application.

2.1.3.1 Preventive Control Techniques. Preventive paved road controls play a very important role in reducing contaminated particulate emissions at TSDFs. The two most likely contributors to contaminated surface loadings--spillage and carry-out from nearby operational areas--are undoubtedly better controlled at their source rather than by attempting to clean the surface of the deposits. Furthermore, in the case of gross particulate emissions, preventive measures may also provide a more cost-effective control program than mitigative measures. An outline of preventive measures applicable for TSDFs is provided in Table 2-4. Each alternative is discussed in Section 2.1.4.

TABLE 2-4. OUTLINE OF PREVENTIVE PAVED ROAD CONTROL MEASURES APPLICABLE TO TSDFs

- Spills from haul truck
  - --require loads to be covered
  - --wet loads prior to transport
  - --require a minimum amount of freeboard to be maintained

- Carry-out from other operational areas
  - --semicontinuous cleanup of access point
  - --vehicle wash or grizzly at exit
  - --pave access point
  - --redistribution of traffic patterns (e.g., strict enforcement of one-way routes) in operational areas to reduce trackout

- Wind/water erosion from adjacent areas
  - --vegetative stabilization of open areas
  - --physical controls (e.g., wind breaks or storm water ditches, etc.)

The major drawback in designing and assessing the performance of preventive control programs is due to the fact that there are few, if any, efficiency values associated with the measures. Because these types of controls attempt to prevent deposition of additional material onto paved surfaces, quantitative measurements before and after control implementation are generally not feasible. Furthermore, interpretation of what data are available is often complicated.

Instead of requiring control effectiveness estimates for preventive measures at TSDFs, regulators may prefer to require responsible parties to list in their Part B "Wind Dispersal Flow Control Plan" all paved road preventive measures contemplated for use at their facility. While data are generally not available to document the effectiveness of these measures, regulators may in that case choose to require a systematic field sampling program (of the type discussed in Section 2.1.5) to demonstrate that the mean silt loading does not exceed a permit-specified value (for example, 5 g/m²). (Note that the regulatory agency should also reserve the right for their own spot inspections of silt loading.) Should the specified value be exceeded, the permit would contain provisions calling for more strenuous implementation of preventive (and possibly mitigative) controls as well as a more intensive field sampling program to demonstrate compliance with the permitted limit.

2.1.3.2 Mitigative Control Techniques. While preventive controls are to be preferred for contaminated particulate emission control, preventive measures may not be able to provide the gross particulate control effectiveness desired at a TSDF. Furthermore, in the context of the mitigative vs. preventive distinctions made in Section 1 of this document, mitigative measures are required to reduce contaminated emissions due to the background metals and organics levels inherent with the long-term waste disposal operations at the TSDF.

Generally recognized mitigative controls for paved roads were presented in Table 2-4, with the controls falling in the categories of:

- Broom sweeping: This control employs mechanical cleaning of the travel surface. Much of the effect may be viewed as "cosmetic," in the sense that, while the roadway appears to be much cleaner, a substantial fraction of the original loading may be emitted to the atmosphere during the cleaning process.[4] Because there is credence to the claim that broom sweeping is as much a source as it is a control of particulate emissions, the *possible increase in contaminated* particulate emissions without provision for capturing that mass may preclude further consideration of this control. Regulators should be advised, however, that broom sweeping may provide the only mitigative paved road control measure that is feasible throughout the year in all portions of this country.
- Vacuum sweeping: Material may also be removed from the travel surface by entraining particles in a moving air stream. Hoppers contain the material collected. In an open system, air exhausts through a filter; in closed systems, the air is continuously recycled.[4]
- Water flushing: Street flushers remove surface loadings under the action of high-pressure water sprays. Some systems supplement the

cleaning process with broom sweeping after flushing (sweeping emissions are thus wet-suppressed).*

2.1.4 Control Performance Estimation/Specification

2.1.4.1 Preventive Measures.

Spillage from haul trucks and waste carriers--Because spillage during the transport of wastes and other materials causes some of the road loadings present on paved roads at TSDFs, it is clear that better control of spillage will reduce particulate emissions from those roads. In terms of contaminated particulate, it is equally clear that control of waste haulers (including plant traffic hauling stabilized and other treated waste) is of primary importance. What is not clear in these situations, however, is how much of the surface silt loading on a paved road can be attributed to spillage. Without that final piece of information, reliable estimation of the control efficiency afforded by spillage controls is unlikely.

Because of the difficulty in assessing the effectiveness of this type of control and because reasonable requirements in permits to prevent spillage should not be considered overly restrictive, it is recommended that *all* wind dispersal flow control plans contain provisions to effectively eliminate spillage of wastes onto paved roads. This could be accomplished by (1) specifying covered or enclosed trucks or minimal freeboard requirements, (2) accepting no loads from haulers exhibiting visible spillage, (3) requiring all accidental spills to be reported immediately to the operations manager, and (4) rerouting traffic around any accidental spills which will be cleaned as soon as possible (and in any case less than, say 8 hours).

Carryout from adjacent unpaved areas--Mud and dirt carryout from operational areas, as well as the spreading of contaminated material from those areas, can account for a large fraction of the total surface loading on paved roads at TSDFs. Preventive control measures applied to this source of road loadings can result in substantially lower gross and contaminated particulate emission levels.

As was the case for spillage controls, reliable estimation of the effectiveness of carryout control programs is not generally possible. Quantification of control efficiencies for preventive techniques is essentially impossible using the standard "before and after" measurement approach. Furthermore, tracking of material onto a paved roadway results in a great deal of spatial variation in loading about the access point. This variation in loading complicates the modeling of emission reductions as well as the simple estimation of the efficiency. The methodology described below will result in *upper bounds of emission reductions*. That is, the control afforded by carryout prevention cannot be easily described in terms of percent reduction but rather is discussed in terms of mass emissions prevented.

For an individual access point from an unpaved operational area to an adjacent paved road, let N represent the daily number of vehicles leaving the area. Let E be given by*

$$E^+ = \begin{array}{l} 36 \ (N \le 25) \\ 91 \ (N > 25) \end{array} \qquad (2\text{-}5)$$

Here, E^+ is the *unit* PM_{10} emission increase in g/vehicle.[2] Finally, if M represents the daily number of total vehicle passes on the adjacent paved road, then $E^+ \times M$ is the total increase in PM_{10} emissions due to carryout.** Assuming complete prevention of carryout, then $E^+ \times M$ also represents the effective emission reduction.

The emission reduction calculated above assumes that essentially all carryout from the operational area is controlled and, as such, should be viewed as an upper limit. In use, regulators may choose to assign an effective level of carryout control by assuming that only a fraction of the total is controlled.

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*The carryout emission factors presented in Reference 2 were based on the urban paved road model (presented in Table 2-2). The values given in Equation 2-5 are based on a revision of the underlying data using the industrial paved road model (as given in Table 2-2).

**The emission increase in *contaminated* particulate matter can be estimated as $\alpha_j \times E^+ \times M$, where α_j is the contamination level for the compound j in the operational area's surface material.

Methods used to control carryout consist of mitigative measures on the paved surface or preventive measures applied at the operational areas. Discussion of mitigative approaches are discussed in Section 2.1.4.2 of this chapter; preventive measures applied at operational areas are discussed in the remaining sections of this report.

As noted earlier, instead of requiring control effectiveness estimates for preventive measures as TSDFs, regulators may prefer to require responsible parties to list in their Part B "Wind Dispersal Flow Control Plan" all paved road preventive measures contemplated for use at their facility. Regulators may choose to require in the permit that the responsible parties conduct a systematic field sampling program (of the type discussed in Section 2.1.5) to demonstrate that the mean silt loading does not exceed a permit-specified value (for example, 5 g/m²). Should this value be exceeded, the permit would contain provisions calling for more strenuous implementation of preventive (and possibly mitigative) controls as well as a more intensive field sampling program to demonstrate compliance with the permitted limit.

Other preventive measures--Numerous other preventive controls could be applied to paved roads at TSDFs, ranging from wind fences to prevent material from operational areas being blown onto the roadways to the installation of stormwater controls. No data are known to exist that quantify the PM_{10} emissions reductions attributable to these measures. It is recommended that regulators require responsible parties to list in their Part B "Wind Dispersal Flow Control Plan" all paved road preventive measures contemplated for use at their facility. Because data are generally not available to document the effectiveness of these measures, regulators may again require in the permit that the responsible parties conduct a systematic field sampling program of the type discussed above. The permit should contain provisions for more strenuous preventive (and possibly mitigative) controls, should the field sampling program demonstrate noncompliance with the permitted limit.

2.1.4.2 Mitigative Control Techniques. Although the preventive measures described earlier can be viewed as very cost-effective, these measures alone may not be able to provide the total paved road emissions reduction sought (see the discussion in Section 2.1.5). Furthermore, in the context of controlling contaminated particulate emissions, mitigative controls can be considered as a "second line of defense" in safeguarding public health and the environment. This section discusses the effectiveness of mitigative paved road control techniques.

Broom sweeping of roads--Mechanical street cleaners employ rotary brooms to remove surface materials from roads and parking lots. Much of their effect is cosmetic in that, while the roadway appears much cleaner, a substantial fraction of the original loading is emitted during cleaning. Thus, "dry" broom sweeping is not recommended as a means of removing surface material from roads.

Vacuum sweeping of roads--Vacuum sweepers remove material from paved surfaces by entraining particles in a moving air stream. A hopper is used to contain collected material and air exhausts through a filter system in a open loop. A regenerative sweeper functions in much the same way, although the air is continuously recycled. In addition to the vacuum pickup heads, a sweeper may also be equipped with gutter and other brooms to enhance collection.

Control efficiency values were given earlier in Table 2-3. Available data show considerable scatter, ranging from a field measurement showing no effectiveness (over baseline uncontrolled emissions) to another field measurement of 58%. An average of the field measurements would indicate a efficiency of 34%. In addition, the estimated upper limits for PM_{10} control of urban roads compare fairly well with that average. Because adequate controlled emission estimates can be obtained using the models given in Section 2.1.2, it is recommended that material loading samples be employed, if possible, in conjunction with the model to obtain better estimates of control effectiveness.

Cost elements involved with vacuum sweeping include the following capital and operating/maintenance (O&M) expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts, truck maintenance, operator labor cost

Data presented in Reference 5 provides the following estimates for a vacuum sweeping program:

Initial capital expense: 36,800 $/truck

Annual O&M expense: 34,200 $/truck

All costs are based on April 1985 dollars. Determination of the number of trucks necessary can be made by assuming that 4 mi can be swept per unit per 8-h shift.[6] Additional cost data for a vacuum sweeping program is provided in Table 2-5. Note that, unlike the public and industrial paved road estimates given above, the cost data in Table 2-5 are based on actual values reported by an industrial plant during the first few years of an intensive road-cleaning program.

TABLE 2-5. MISCELLANEOUS OPERATION/DESIGN AND COST DATA FOR VACUUM SWEEPING PAVED ROADS[a]

Purchase price:	$72,000 (1980)
Estimated life expectancy:	5 yr
Approximate annual operating cost during 1981:	$214,000
Fuel consumption:	4 mi/gal
Hopper capacity:	10 yd^3
Vacuum blower capacity:	12,000 ft^3/min
Vehicle weight:	32,000 lb
Width of area cleaned per pass:[b]	5 ft
Normal sweeping speed:	5 mi/h
Velocity at suction head:	NA
Type of dust control system (i.e., wet or dry):	Wet

[a] Reference 6. Purchase cost is actual cost in year purchased; other costs in 1981 dollars.

[b] Multiple passes required.

Enforcement of a vacuum sweeping dust control program would ideally consist of two complementary approaches, record keeping and field inspection. The first requires the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular cleaning program is in place. The second approach involves agency spot checks of controlled roads by taking a material sample from the road. As before, the second approach is discussed in greater detail in Section 2.1.5. Note that some sample collection may be necessary to estimate control performance.

Records must be kept that document the frequency of vacuum sweeping paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency.

2. Length of each road and area of each parking lot.

3. Type of control applied to each road/area and planned frequency of application.

4. Any provisions for weather (e.g., 1/4-in of rainfall will be substituted for one treatment, etc.).

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets).

3. Start and stop times on a particular segment/parking lot, average speed, number of passes.

4. Qualitative description of loading before and after treatment.

5. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

General Records to be Kept

1. Equipment maintenance records.

2. Meteorological log (to the extent that weather influences the control program--see above).

3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested in Section 2.1.5 require that additional records be kept. These records may include surface material samples or traffic counts. Traffic counts may be recorded either manually or using automatic devices.

Water flushing of roads--Street flushers remove surface materials from roads and parking lots using high pressure water sprays. Some systems supplement the cleaning with broom sweeping after flushing. Note that the purpose of the program is to remove material from the road surface; in some industries, water is regularly applied to roads to directly control emissions (i.e., as in unpaved roads). Unlike the two sweeping methods, flushing faces some obvious drawbacks in terms of water usage, potential water pollution, and the frequent need to return to the water source. However, flushing generally tends to be more effective in controlling particulate emissions. Caution must be exercised in flushing near access points to operational areas. As noted above, watering may increase the spreading of contamination from operating areas onto paved roads. Furthermore, if the paved roads are already contaminated, flushing may pose additional problems in terms of surface and ground-water contamination.

Equations to estimate instantaneous control efficiency values were given in Table 2-3. Note that water flushing and flushing followed by broom sweeping represent the two most effective control methods (on the basis of field emission measurements) given in that table.

Cost elements involved with broom sweeping include the following capital and operating/maintenance (O&M) expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts (possible including brushes), truck maintenance, operator labor, water

Cost data presented in Reference 5 provides the following estimates for a flushing program:

Initial capital expense: 18,400 $/truck

Annual O&M expense: 27,600 $/truck

All costs are based on April 1985 dollars. Determination of the number of trucks required can be based on the assumption that 3 to 5 mi can be flushed or flushed and broom swept per unit per 8-h shift, respectively.[6] Additional cost/design data are provided as Table 2-6. As before, the data in the table represent actual reported costs at an industrial plant.

Enforcement of a road flushing (possibly supplemented by broom sweeping) program could consist of two approaches, as before. The first requires the owner to maintain adequate records that document that a regular cleaning program is in place. The second involves agency spot checks of controlled roads by taking a material sample from the road. While resulting estimates (using the models in Table 2-2 in Section 2.1.2) of controlled emissions should be adequate for a flushing program, the estimates are probably substantially overestimated in a flushing/broom sweeping program.[2]

Records must be kept that document the frequency of water flushing of paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency.
2. Length of each road and area of each parking lot.
3. Type of control applied to each road/area and planned frequency of application.
4. Provisions for weather (e.g., program suspended for periods of freezing temperatures).

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.
2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets).
3. Start and stop times on a particular segment/parking lot, average speed, number of passes.
4. Start and stop times for refilling tanks.
5. Qualitative description of loading before and after treatment.
6. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

TABLE 2-6. MISCELLANEOUS OPERATION/DESIGN AND COST DATA FOR FLUSHING/BROOM SWEEPING PAVED ROADS[a]

Purchase price:	$68,000 (1976)
Estimated life expectancy:	10 yr
Approximate annual operating cost during 1981:	$57,000
Vehicle weight (dry):	NA lb
Water tank capacity:	8,000 gal
Normal vehicle speed:	4 mi/h
Water pressure at nozzles:	50 psig
Vehicle weight (wet):	NA lb
Fuel consumption:	7 mi/gal
Water flow at nozzles:	188 gal/min
Hopper capacity:	40 yd³
Daily water consumption:	30,000 gal
Degree of water treatment:	1,800 gal/mil

[a] Reference 6. Purchase cost is actual cost in year purchased; other costs in 1981 dollars.

General Records to be Kept

1. Equipment maintenance records.
2. Meteorological log (to the extent that weather influences the control program--see above).
3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested in Section 2.1.5 require that additional records be kept. These records may include surface material samples or traffic counts.

2.1.5 Procedures for Compliance Determination

Record review of control programs (e.g., vacuum sweeping, etc.) and field checks (i.e., road silt loading sampling) will provide the likely means of compliance determination for these sources. Because paved road emissions are directly related to the surface silt loading, the most reliable regulatory formats are based on loading. Formats viable for other open dust sources--including opacity measurements, visible emissions at the property line--are generally not applicable for paved roads because of the lower unit emission levels involved (e.g., there are usually no visible plumes from a vehicle pass).

An alternative format is presented below to suggest how a quantitative method could be incorporated in a regulation. If the silt loading on a road ever exceeds the "action level" silt loading specified in a permit, the regulatory agency may require the responsible party to reduce the silt loading to a level less than the action level. The action level may be an agency-supplied multiple of either baseline measurements or values provided in Table 2-1 and should correspond to maximum allowable emission factors. The means of reduction will be left to the discretion of the responsible party and could consist of either preventive or mitigative controls. The maximum allowed silt loading requirement could be made part of an operating permit. Note that these action levels could be specific to individual roads, apply to all roads in a plant, or be based on plant traffic levels. Because some TSDFs may contain many paved roads, the regulatory agency may choose to set plant-wide goals (such as vacuum sweeping each road twice per week) rather than source-specific programs.

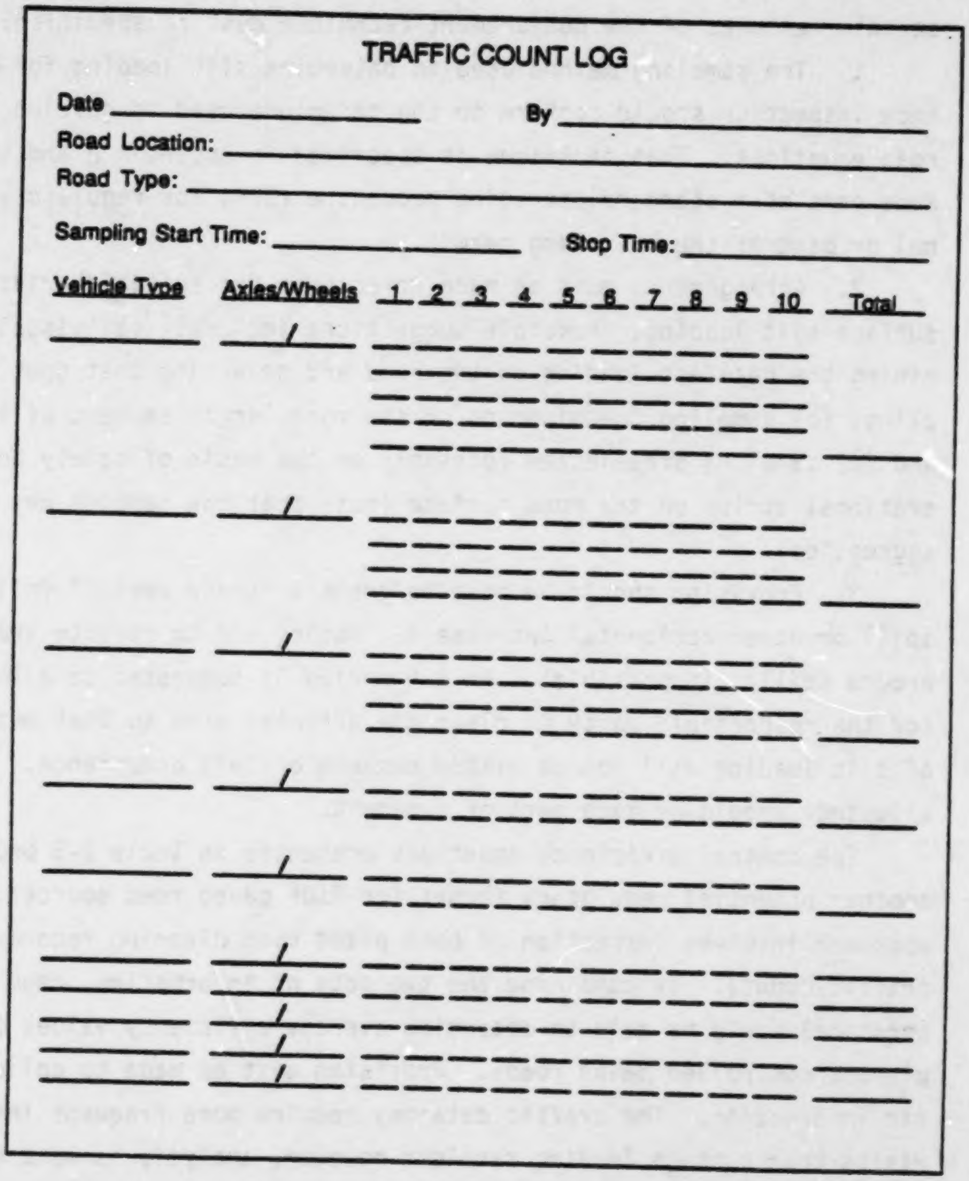
The field measurement of silt loading could either be made a requirement of the responsible party or be assigned to agency inspection personnel, or a combination of the two could be used. In either event, certain features of the measurement technique must be specified:

1. The sampling method used to determine silt loading for compliance inspection should conform to the technique used to develop the paved road equations. That technique is specified in Appendix D and should be made part of a standard operating procedure (SOP) for regulatory personnel or part of the operating permit.

2. Arrangements must be made to account for spatial variation of surface silt loading. Possible suggestions include: (a) visually determining the heaviest loading on the road and selecting that spot for sampling, (b) sampling the midpoint of the road length segment of interest, and (c) sampling preselected (possibly on the basis of safety considerations) strips on the road surface (note that the samples may be aggregated).

3. Provision should be made to grant a "grace period" following a spill or other accidental increase in loading and to reroute traffic around spills (if possible). An 8-h period is suggested to allow time for the responsible party to clean the affected area so that measurements of silt loading will not be biased because of this occurrence. This time allowance snould be made part of a permit.

The control efficiency equations presented in Table 2-3 provide another potential regulatory format for TSDF paved road sources. This approach involves inspection of both plant road cleaning records and traffic counts. By combining the two sets of information, regulatory personnel would be able to determine average efficiency values for the plant's controlled paved roads. Provision must be made to collect traffic information. The traffic data may require more frequent inspection visits than surface loading samples; however, analysis is more easily accomplished. Surface loading sampling provides an additional means for checking the success of achieving the estimated control efficiency. Sample data forms for traffic counts and silt loading measurements given as Figures 2-1 and 2-2, respectively.



TRAFFIC COUNT LOG

Date ____________ By ____________

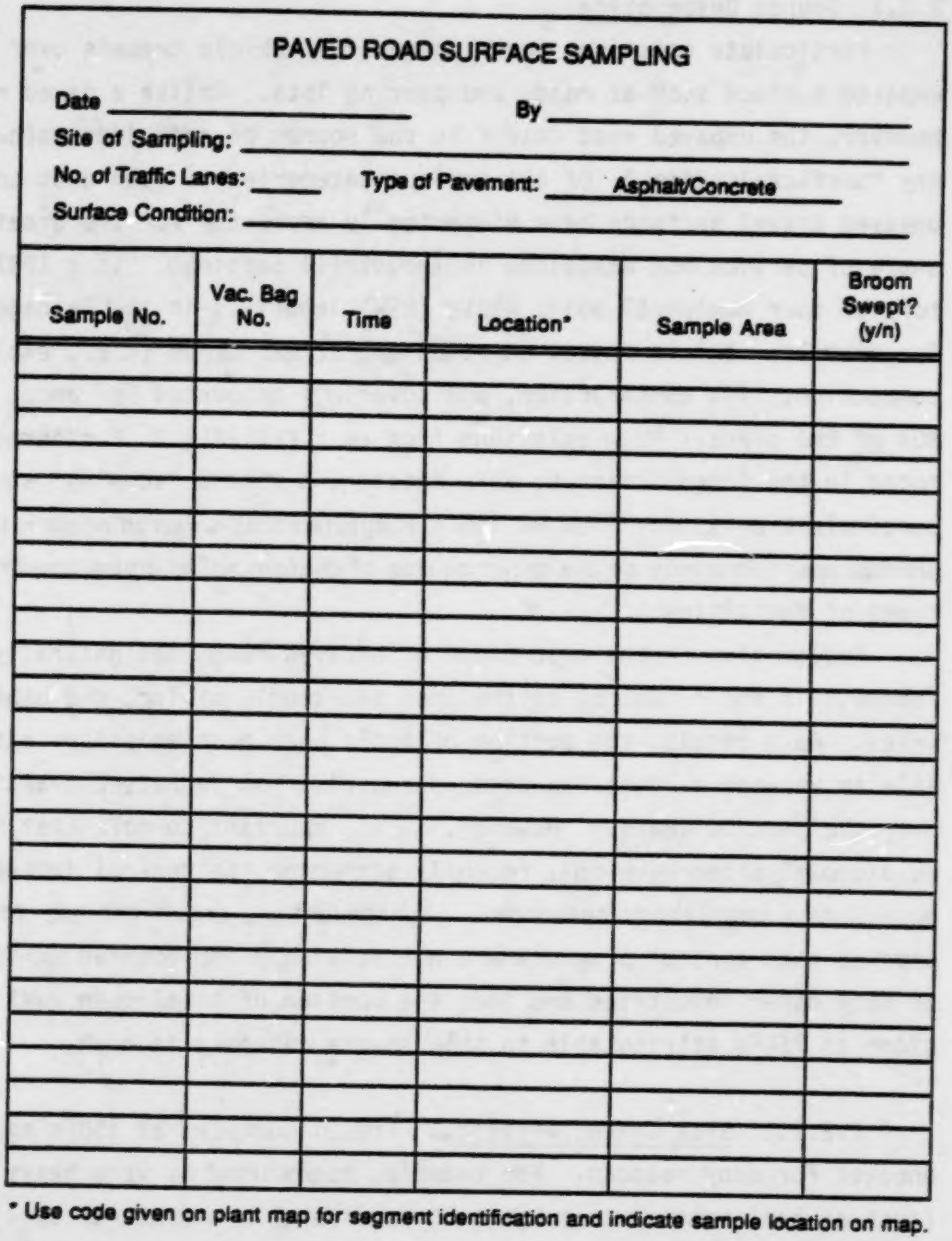
Road Location: ____________

Road Type: ____________

Sampling Start Time: ____________ Stop Time: ____________

Vehicle Type	Axles/Wheels	1	2	3	4	5	6	7	8	9	10	Total
	/											
	/											
	/											
	/											
	/											
	/											
	/											
	/											
	/											

Figure 2-1. Traffic count log.



PAVED ROAD SURFACE SAMPLING

Date ____________ **By** ____________

Site of Sampling: ____________

No. of Traffic Lanes: ____ **Type of Pavement:** Asphalt/Concrete

Surface Condition: ____________

Sample No.	Vac. Bag No.	Time	Location*	Sample Area	Broom Swept? (y/n)

* Use code given on plant map for segment identification and indicate sample location on map.

Figure 2-2. Sampling data form for paved roads.

2.2 UNPAVED ROADS

2.2.1 Source Description

Particulate emissions occur whenever a vehicle travels over an unpaved surface such as roads and parking lots. Unlike a paved road, however, the unpaved road itself is the source of emissions rather than any "surface loading." Of the various categories of open dust sources, unpaved travel surfaces have historically accounted for the greatest share of particulate emissions in industrial settings. In a 1987 inventory of four municipal solid waste (MSW) landfills in the Chicago area, for example, vehicle travel on roads and access areas (i.e., exclusive of compaction, lift construction, and covering) accounted for about 70% to 80% of the overall PM_{10} emissions from each facility.[7] Furthermore, as noted in the introduction to this chapter, a recent "scoping" study of particulate emissions from HW TSDFs *suggested that unpaved roads rather than process operations may be the major source of contaminated emissions* from these types of facilities.[1]

Recognition of the importance of unpaved roads led naturally to an interest in their control by the iron and steel, mining, and other industries. As a result, the portion of total open dust emissions attributable to unpaved surfaces in those industries has decreased dramatically over the past 10 years.[8] However, it is important to note that MSW and HW disposal sites have only recently attracted the general interest of *air pollution* regulatory personnel. Consequently, one might expect that unpaved road control programs are not as widely implemented at TSDFs as in many other industries and that the portion of total open dust emissions at TSDFs attributable to this source category is high.

2.2.1.1 Site Characteristics. Travel surfaces at TSDFs may be unpaved for many reasons. For example, roads used by very heavy vehicles (such as haul trucks) or subject to considerable amounts of spillage of cover and other materials during transport operations are not suitable candidates for paving. Some roads are used for only short periods of time to access certain disposal areas; other more permanent roads may have poorly constructed bases. In either case, paving is impractical.

Temporary roads can often be controlled more cost-effectively by regular watering, while permanent roads could be controlled using regular watering or chemical dust suppressants.

In addition to roadways, TSDFs generally contain important unpaved travel *areas*. Examples include access areas proximate to treatment and disposal areas and haul truck traffic patterns related to the stockpiling of cover and other materials. These areas may account for a substantial fraction of the total traffic-generated emissions at a facility. Furthermore, travel areas tend to be more difficult to control than roadways (e.g., changing traffic patterns make semipermanent controls impractical, increased shear forces from cornering vehicles rapidly deteriorate chemically controlled surfaces, etc.).

2.2.1.2 Dust Emitting Activities. Loose material on roadways and travel areas may become entrained from activities other than vehicular traffic (erosion during high wind events, for example). The principal long-term source of emissions for *roads* is, of course, vehicle travel. Only travel-related emissions are considered in the remainder of this chapter. Other travel areas can be considered open areas, with wind erosion emissions estimated following the discussion in Section 3.0 of this manual.

2.2.1.3 Potential Contamination Problems. As mentioned above, an earlier study of HW TSDFs suggested that unpaved roads may be the principal source of metals and semivolatile organic emissions at these types of facilities. Contaminants in the loose surface aggregate of the roadway may be due to spillage during transport of HW or track-on of material which has become contaminated because of the various unit operations at the facility. Both of those sources may be at least partially controlled by instituting better operating practices at the facility. Again (as discussed in this section's introduction), it is important to note that control measures designed to reduce emissions at a unit operation may actually compound contaminated emissions on adjacent roadways.

2.2.2 Estimation of Uncontrolled Emissions

2.2.2.1 Estimation of Uncontrolled Particulate Emissions.

Estimation of the uncontrolled particulate emission rate R from unpaved TSDF roadways follows the general emission model presented as Eq. 1-2:

$$R = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} e_i A_i \tag{2-6}$$

where:
R_i = emission rate associated with the i-th road segment
e_i = emission factor applicable for the i-th road segment
A_i = source extent, in terms of vehicle distance traveled on road segment i over the averaging time of interest
n = number of road segments

Unlike paved roads, emission estimates for unpaved surfaces do not require a "decision" process involving surface/vehicle parameters because the AP-42 emission factor equation takes source characteristics into consideration:[3]

$$e = 0.61 \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{(365-p)}{365} \quad \text{(kg/VKT)}$$

$$e = 2.1 \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{(365-p)}{365} \quad \text{(lb/VMT)} \tag{2-7}$$

where:
e = PM_{10} emission factor in units stated
s = silt content of road surface material, percent
S = mean vehicle speed, km/h (mi/h)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels (dimensionless)
p = number of days with $\geq$ 0.254 mm (0.01 in) of precipitation

Site-specific input parameters are strongly recommended; if this is not feasible, a summary of measured values is presented as Table 2-7.

TABLE 2-7. POSSIBLE DEFAULT VALUES FOR UNPAVED ROAD ESTIMATES AT TSDFs[a]

Parameter (units)	Probable range	Possible default
Silt content (%)	2-20	8[b]
Average vehicle		
--Speed (kph)	8-45	20[b]
--Weight (Mg)	8-40	25[b]
--No. of wheels	4-18	10[b]

[a] Based on observations during inventories of HW and MSW landfills.

[b] As noted in text, use of site-specific data is *strongly recommended.*

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 2-3 gives the geographical distribution of the mean annual number of wet days per year in the United States. Maps giving similar data on a monthly basis are available from the U.S. Department of Commerce.[9]

It is important to note that for the purpose of estimating annual or seasonal controlled emissions from unpaved roads, average control efficiency values based on worst case (i.e., dry, $p = 0$ in Eq. 2-7) uncontrolled emission levels are required. This is true simply because the predictive emission factor equation for unpaved roads, which is routinely used for inventorying purposes, is based on source tests conducted under dry conditions.[3] Extrapolation to annual average uncontrolled (including natural mitigation) emissions estimates is accomplished by assuming that emissions are occurring at the estimated rate on days without measurable precipitation, and conversely are absent on days with measurable precipitation. This assumption has never been verified in a rigorous manner; however, MRI's experience with hundreds of field tests indicate that it is a reasonable assumption if the source operates on a fairly "continuous" basis.

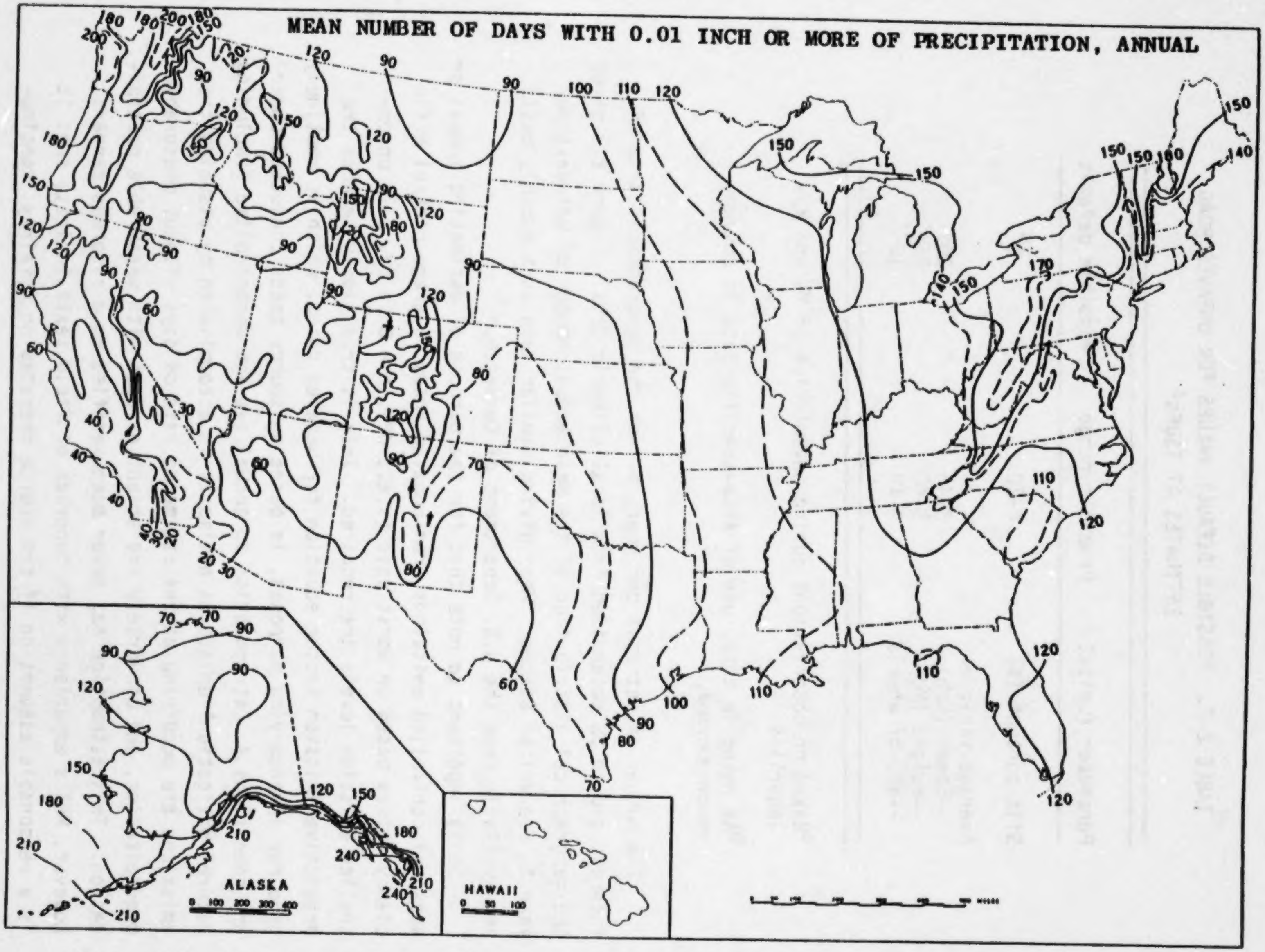

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF PRECIPITATION, ANNUAL
ALASKA
0 100 200 300 400
HAWAII
0 50 100
200
180
150
120
110
100
90
80
70
60
40
30
20
240
210
170
140

Figure 2-3. Mean annual number of days with at least 0.01 in of precipitation. As noted in Reference 2, patterns are too complex in Hawaii for inclusion on map. (Means for Hilo, Honolulu, and Lihue are 148, 204, and 90 days per year, respectively.)

The uncontrolled emission factor for a specific unpaved road will increase substantially after a precipitation event as the surface dries. However, in the absence of data sufficient to describe this growth as a function of traffic parameters, amount of precipitation, time of day, season, cloud cover, and other variables, uncontrolled emissions are estimated using the simple assumption given above. Prior MRI testing has suggested that for unpaved travel areas, surface moisture levels approximately twice that for dry conditions afford control of roughly 75% to 90%.[2] Between the dry, uncontrolled moisture level (typically < 2%) and approximately 3% to 4%, a small increase in moisture content may result in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. These relationships are discussed in greater detail in Section 2.2.3.

2.2.2.2 Estimation of Contaminated Particulate Emissions. The emission rate R_j of particulate contaminated with compound j can be represented as

$$R_j = \sum_{i=1}^{n} R_{ij} = \sum_{i=1}^{n} \alpha_{ij} e_i A_i \qquad (2\text{-}8)$$

where the terms are as defined above and:

R_{ij} = emission rate of contaminant j from road segment i

α_{ij} = fraction of contaminant j in the particulate emissions from road i

The guidelines for estimating α_{ij} presented earlier in Section 2.1.2.2 are applicable here. It is *strongly recommended* that material samples be taken from the road surfaces in the TSDF, and that the silt (i.e., ≤ 200 mesh) fraction be analyzed for the compounds of interest.

2.2.3 Demonstrated Control Techniques

While there are numerous control options for unpaved roads, the differences between preventive and mitigative measures are not as easily defined for this source category as compared to paved roads. Paved road emissions are directly related to the *amount* of loose material present per unit area of the road surface, and preventive measures reduce that amount. Emissions from uncontrolled unpaved roads, on the other hand, depend on the *texture* of the road surface rather than the amount of material present. Thus, the term "preventive," as applied to unpaved roads, does not connote the same idea of necessarily reducing a variable which directly affects emissions.

Furthermore, in the context of contaminated particulate emissions from unpaved surfaces, "preventive" is possibly best considered as representing those techniques which reduce carryout and spillage of *contaminated* materials onto the unpaved road surface, and any other measure that reduces both gross and particulate emissions from the roadway could be considered "mitigative."

2.2.3.1 Preventive Measures. While the effects of carryout and spillage are much more pronounced on paved rather than unpaved surfaces, preventing contamination of the travel surface is equally important in either case. As such, the discussion of preventive measures in Section 2.1.3.1 is equally applicable here, with sole *exception that contamination of the silt fraction* of the road surface rather than the "gross" surface loading should be the variable of interest in field determinations. This is discussed in greater detail in Section 2.2.4.

2.2.3.2 Mitigative Measures. Three broad categories of unpaved road control options are presented in Table 2-8; each is discussed in greater detail in the following sections.

Source extent reductions--These controls either limit the amount of traffic on a road to reduce the PM_{10} emission rate or lower speeds to reduce the emission factor value given by Eq. 2-7. Examples might include restriction of some roads to only certain vehicle types, or strict enforcement of speed limits. In any instance, the control afforded by these measures is readily obtained by the application of Eq. 2-7.

TABLE 2-8. CONTROL TECHNIQUES FOR UNPAVED TRAVEL SURFACES

Source extent reduction:	Speed reduction Traffic reduction
Source improvement:	Paving Gravel surface
Surface treatment:	Watering Chemical stabilization[a] --Asphalt emissions --Petroleum resins --Acrylic cements --Other

[a] See Table 2-9.

Surface improvements--These controls alter the road surface. Unlike surface treatments (discussed below), these improvements are largely "permanent"; that is, frequent periodic retreatments are not normally required.

The most obvious surface improvement is, of course, paving an unpaved road. This option is expensive and is probably most applicable to high volume (more than a few hundred passes per day) roads at TSDFs which are used every day (i.e., not those providing temporary access to areas). Clearly, control efficiency estimates can be obtained by applying the information of Section 2.1 of this manual.

Other improvement methods cover the road surface material with another material of lower silt content (e.g., covering a dirt road with gravel or slag, or using a "road carpet" under ballast). Because Eq. 2-7 shows a linear relationship between the emission factor and the silt content of the road surface, any reduction in the silt value is accompanied by an equivalent reduction in emissions. This type of improvement is initially much less expensive than paving; however, periodic maintenance (such as grading and spot reapplication of the cover material) may be required.[4]

TABLE 2-9. CHEMICAL STABILIZERS[a]

A. Type: Bitumens

Product	Manufacturer
AMS 2200, 2300®	Arco Mine Sciences
Coherex®	Witco Chemical
Docal 1002®	Douglas Oil Company
Peneprime®	Utah Emulsions
Petro Tac P®	Syntech Products Corporation
Resinex®	Neyra Industries, Inc.
Retain®	Dubois Chemical Company

B. Type: Salts

Product	Manufacturer
Calcium chloride	Allied Chemical Corporation
Dowflake, Liquid Dow®	Dow Chemical
DP-10®	Wen-Don Corporation
Dust Ban 8806®	Nalco Chemical Company
Dustgard®	G.S.L. Minerals and Chemicals Corporation
Sodium silicate	The PQ Corporation

C. Type: Adhesives

Product	Manufacturer
Acrylic DLR-MS®	Rohm and Haas Company
Bio Cat 300-1®	Applied Natural Systems, Inc.
CPB-12®	Wen-Don Corporation
Curasol AK®	American Hoechst Corporation
DCL-40A, 1801, 1803®	Calgon Corporation
DC-859, 875®	Betz Laboratories, Inc.
Dust Ban®	Nalco Chemical Company
Flambinder®	Flambeau Paper Company
Lignosite®	Georgia Pacific Corporation
Norlig A, 12®	Reed Lignin, Inc.
Orzan Series®	Crown Zellerbach Corporation
Soil Gard®	Walsh Chemical

[a] Source: Reference 10, as cited by Reference 11.

Surface treatments--Surface treatment refers to those control techniques which require periodic reapplications. Treatments fall into the two main categories of (1) wet suppression (i.e., watering, possibly with surfactants or other additives), which keeps the surface wet to control emissions, and (2) chemical stabilization, which attempts to change the physical (and, hence, the emissions) characteristics of the roadway. Necessary reapplication frequencies may range from several minutes for plain water under hot, summertime conditions to several weeks (or months) for chemicals.

As is the case for water flushing paved roads, care must be exercised in order to prevent contamination of the road surface by track-out from operational areas. Furthermore, watering an already contaminated road and adding chemicals to the road surface may pose serious ground and surface water problems. Consequently, the use of surface treatments must be assessed on a site-specific basis.

Water is usually applied to unpaved travel areas using a truck with a gravity or pressure feed. This is only a temporary measure, and periodic reapplications are necessary to achieve any substantial level of control efficiency. Some increase in overall control efficiency is afforded by wetting agents which reduce surface tension.

Chemical dust suppressants (Table 2-9), on the other hand, have much less frequent reapplication requirements. These suppressants are designed to alter the roadway, such as cementing loose material into a fairly impervious surface (thus simulating a paved surface) or forming a surface which attracts and retains moisture (thus simulating wet suppression).

Chemical dust suppressants are generally applied to the road surface as a water solution of the agent. The degree of control achieved is a function of the *application intensity* (volume of solution per area), *dilution ratio*, and *frequency* (number of applications per unit time) of the chemical applied to the surface and also depends on the type and number of vehicles using the road.

2.2.4 Control Performance Estimation

The discussion of paved road preventive measures in Section 2.1.3.1 applies equally to control techniques to prevent spreading of contamination onto unpaved surfaces. The primary exception in the case of unpaved roads deals with the use of field samples to assess the effectiveness. While silt loading samples afford a relatively inexpensive way to gauge the efficiency of preventive measures applied to paved roads, *contaminant-specific analyses of road silt samples* would be required to directly assess the effectiveness of the same techniques applied to unpaved roads. The expense of this type of analysis may preclude implementation of a routine sampling program. One suggested alternative to estimate the effectiveness of preventive techniques applied to unpaved roads would be (i) require a *paved* road sampling program in the permit and (ii) assume that the same level of efficiency applies to the potential contamination of unpaved roads. Note that this suggested approach assumes that (a) the facility has both paved and unpaved roads subject to spillage and/or carryout from operational areas, (b) analogous control programs are implemented to prevent spillage/carryout onto both the paved and unpaved roads, and (c) the degree of potential (i.e., uncontrolled) spillage and carryout onto paved and unpaved surfaces is comparable.

As with paved roads, it is recommended that *all* wind dispersal flow control plans contain provisions to effectively eliminate spillage of waste onto unpaved roads. This could be accomplished by (1) specifying covered or enclosed trucks or minimal freeboard requirements, (2) accepting no loads from haulers exhibiting visible spillage, (3) requiring all accidental spills to be reported immediately to the operations manager, and (4) rerouting traffic around any accidental spills which will be cleaned as soon as possible (and in any case less than, say, 8 h).

Instead of requiring control effectiveness estimates for measures preventing carryout onto unpaved roads at TSDFs, regulators may prefer to require responsible parties to list in their Part B "Wind Dispersal Flow Control Plan" all measures contemplated for use at their facility. Regulators may choose to require in the permit that the responsible parties conduct systematic field sampling programs for either contaminant-specific determinations of unpaved road silt samples (or possibly of paved road silt loadings as a surrogate, as described above). Should the sampling program ever show that agency-supplied values are exceeded, the permit would contain provisions calling for more strenuous implementation of preventive (and possibly mitigative) controls as well as a more intensive field sampling program to demonstrate compliance with the goals.

2.2.4.1 Source Extent Reductions. These control methods act to reduce the emission rate due to traffic on a road. Control efficiency values are easily obtained by use of Eqs. 2-6 and 2-7.

The reduction may be obtained by banning certain vehicles or strictly enforcing speed limits. Some of these methods may require capital plus operating and maintenance (O&M) expenditures, while others (e.g, speed reductions) may only require indirect costs associated with increased travel times. Consequently, identification of cost elements and estimation of costs are highly dependent upon the option(s) selected to reduce source extent, and no attempt is made here to generalize costs.

2.2.4.2 Surface Improvements.

Paving--Control efficiency estimates for paving previously unpaved roads may be based on the material presented as Section 2.1 of this manual. Inherent in this process is estimating the silt loading on the paved surface; it is recommended that the reader use either values measured from presently paved roads in the facility or the values given in Table 2-1.

Cost elements identified for paving are as follows:

Capital: Operating equipment (graders, paving equipment), paving material (asphalt, concrete), base material

O&M: Patching materials, labor for patching, equipment maintenance

Reference 5 provides the following cost estimates (April 1985 dollars) for asphaltic paving:

Initial capital expense: $44,700-$80,200/mi

Annual O&M costs: $6,600-$11,900/mi

These estimates are based on resurfacing every 5 years and "15 percent opportunity costs." Reference 6 estimates a cost of $140,000/mi (1983 dollars) to pave unpaved roads in the iron and steel industry. Because of the variety of cost estimates, it is strongly recommended that the reader obtain quotes from local paving contractors.

Gravel/slag improvements: As noted earlier, these types of improvements replace the present road surface material with a lower silt content material. Note that this method may increase road maintenance costs as the new aggregate fractures. This cost may be avoided by installing a "road carpet." Because Eq. 2-7 indicates a linear relationship between silt content and emission levels, control efficiency can be estimated by determining the reduction in silt content. For example, if a road with a 12% silt content is recovered with a gravel (with an equilibrium silt content of 5%), then a 58% control efficiency would be expected.

Identified cost elements for these improvements follow:

Capital: Material (including "road carpet," if applicable), application equipment, labor

O&M: Periodic grading including equipment and labor

No cost estimates were found in the reference documents used as the basis for this document. Because of the differences in local availability of cover materials (and civil engineering fabrics) and the amount of surface preparation, compaction, and maintenance required for various road types, it is recommended that the reader obtain quotes from local contractors.

2.2.4.3 Surface Treatments.

Watering--The control efficiency of unpaved road watering depends upon (a) the amount of water applied per unit area of road surface, (b) the time between reapplications, (c) traffic volume during that period, and (d) prevailing meteorological conditions during the period. While several investigations have estimated or studied watering efficiencies, few have specified all the factors listed above.

An empirical model for the performance of watering as a control technique has been developed.[4] The supporting data base consists of 14 tests performed in four states during five different summer and fall months.

The model is:

$$C = 100 - \frac{0.8\ p\ d\ t}{i} \qquad (2\text{-}9)$$

where: C = average control efficiency, percent
p = potential average hourly daytime evaporation rate, mm/h
d = average hourly daytime traffic rate, (h^{-1})
i = application intensity, L/m^2
t = time between applications, h

Estimates of the potential average hourly daytime evaporation rate may be obtained from:

$$p = \begin{cases} 0.0049 \times (\text{value in Figure 2-4}) \text{ for annual conditions} \\ 0.0065 \times (\text{value in Figure 2-4}) \text{ for summer conditions} \end{cases} \qquad (2\text{-}10)$$

Note that no data are available for Alaska and Hawaii in Figure 2-4. Readers responsible for those portions of the country should consult local meteorological resources (e.g., state universities, local weather stations, etc.)

An alternative approach (which is potentially suitable for a regulatory format) is shown as Figure 2-5 which show that between the average uncontrolled moisture content and a value of twice that, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. The relatively simple bilinear relationship shown in the figure is applicable to all particle size ranges considered:[2]

$$c = \begin{cases} 75\ (M-1) & 1 \le M < 2 \\ 62+6.7M & 2 \le M \le \underline{5} \end{cases} \qquad (2\text{-}11)$$

where: c = instantaneous control efficiency, percent
M = ratio of controlled to uncontrolled surface moisture contents

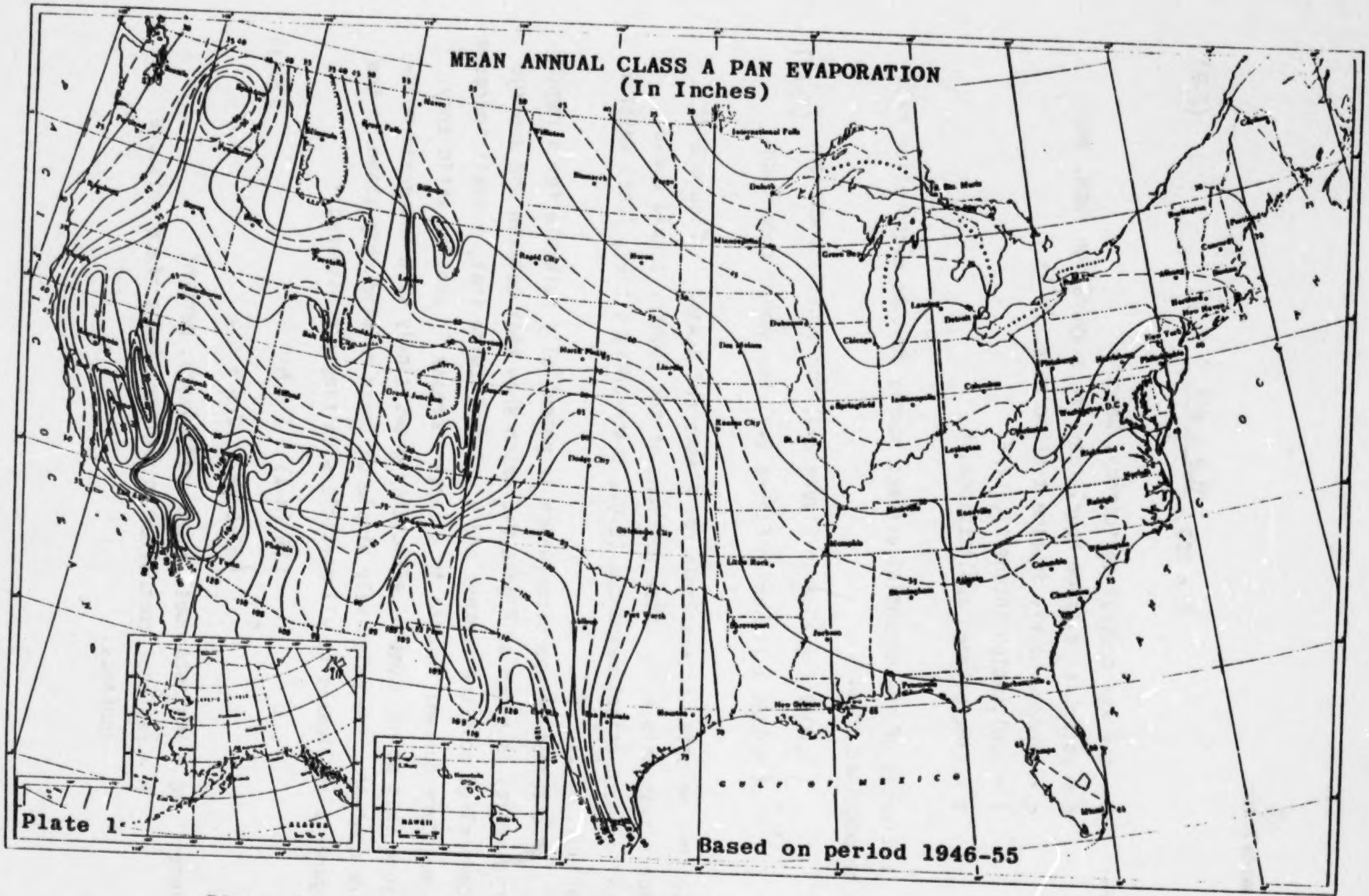

MEAN ANNUAL CLASS A PAN EVAPORATION
(In Inches)
Based on period 1946-55
Plate 1
GULF OF MEXICO
International Falls
Duluth
Rapid City
Des Moines
Chicago
Kansas City
St. Louis
Springfield
Indianapolis
Columbus
Dodge City
Oklahoma City
Little Rock
Fort Worth
Shreveport
New Orleans
Houston
Memphis
Nashville
Atlanta
Jacksonville
Miami
Charleston
Raleigh
Lexington
Pittsburgh
New York
Washington D.C.
Grand Junction
Salt Lake City
Lincoln
Green Bay
Detroit
HAWAII
ALASKA

Figure 2-4. Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).

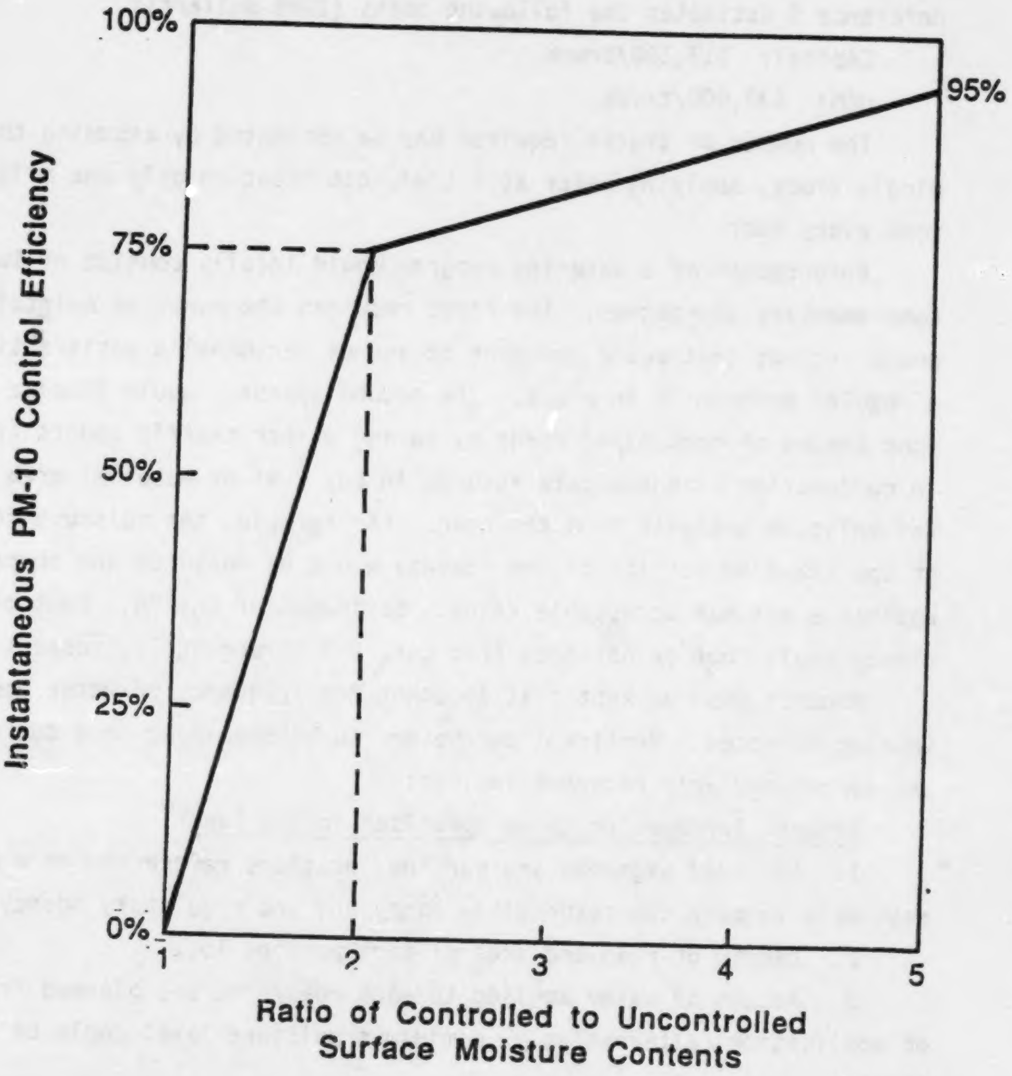


Figure 2-5. Watering control effectiveness for unpaved travel surfaces.

Costs for watering programs include the following elements:

Capital: Purchase of truck or other device

O&M: Fuel, water, truck maintenance, operator labor

Reference 5 estimates the following costs (1985 dollars):

Capital: $17,100/truck

O&M: $32,900/truck

The number of trucks required may be estimated by assuming that a single truck, applying water at 1 L/m², can treat roughly one mile of road every hour.

Enforcement of a watering program would ideally consist of two complementary approaches. The first requires the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular program is in place. The second approach would involve agency spot checks of controlled roads by taking either traffic counts (for use in conjunction with adequate records in Eq. 2-9) or material grab samples for moisture analysis from the road. For example, the moisture content of the traveled portion of the roadway would be measured and compared against a minimum acceptable value. Estimates of the PM_{10} control efficiency could then be obtained from Eqs. 2-9 through 2-11, respectively.

Records must be kept that document the frequency of water applied to unpaved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency.

2. Length of road and area of each parking lot.

3. Amount of water applied to each road/area and planned frequency of application (alternatively, a minimum moisture level could be specified).

4. Any provisions for weather (e.g., 1/4-in of rainfall will be substituted for one treatment; program suspended during freezing periods; watering frequency as a function of temperature, cloud cover, etc.).

5. Source of water and tank capacity.

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.
2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets).
3. Start and stop times on a particular segment/parking lot, average speed, number of passes.
4. Start and stop times for tank filling.

General Records to be Kept

1. Equipment maintenance records.
2. Meteorological log (to the extent that weather influences the control program, see above).
3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested require that additional records be kept. These records may include surface material samples or traffic counts. Traffic counts may be recorded either manually or using automatic devices.

Chemical treatments--As noted earlier, some chemicals (most notably salts) simulate wet suppression by attracting and retaining moisture on the road surface. These methods are often supplemented by some watering. It is recommended that control efficiency estimates be obtained using Figure 2-5 and enforcement be based on grab sample moisture contents.

The more common chemical dust suppressants form a hard cemented surface. It is this type of suppressant that is considered below. Average performance curves have been generated for four common chemical dust suppressants: (a) a commercially available petroleum resin, (b) a generic petroleum resin, (c) an acrylic cement, and (d) an asphalt emulsion. The results of this program were combined with other test results to develop a model to estimate *time-averaged* PM_{10} control performance. This model is illustrated as Figure 2-6. Several items are to be noted:

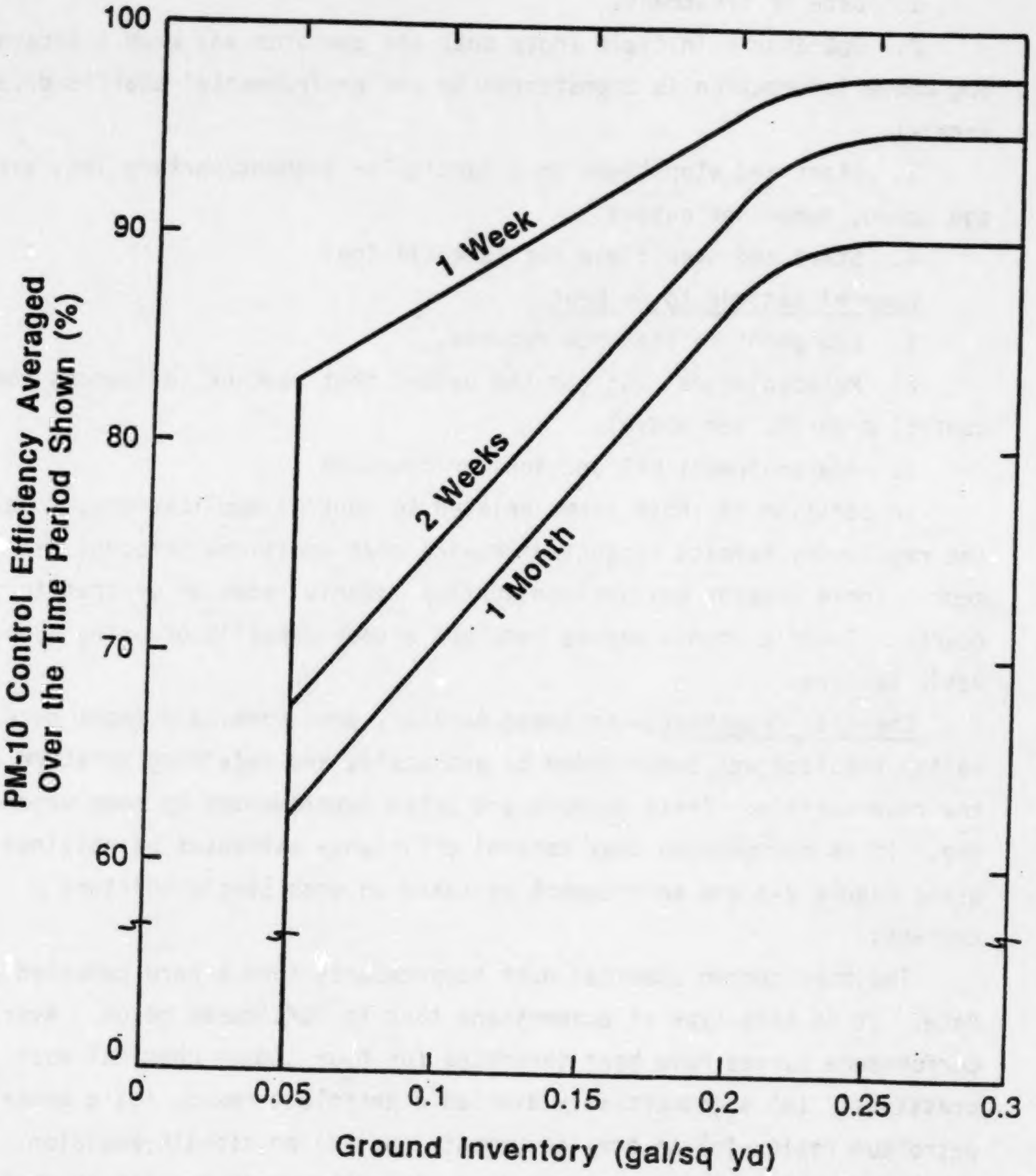


Figure 2-6. Average PM_{10} control efficiency for chemical suppressants.

- The term "ground inventory" is a measure of residual effects from previous applications. Ground inventory is found by adding together the total volume (per unit area) of concentrate (not solution) since the start of the dust control season. An example is provided below.
- Note that no credit for control is assigned until the ground inventory exceeds 0.2 L/m^2 (0.05 gal/yd^2).
- Because suppressants must be periodically reapplied to unpaved roads, use of the time-averaged values given in the figure are appropriate. Recommended minimum reapplication frequencies (as well as alternatives) are discussed later in this section.
- Figure 2-6 represents an *average* of the four suppressants given above. The basis of the methodology lies in a similar model for petroleum resins applied to unpaved roads in the iron and steel industry. However, agreement between the control efficiency estimates given by Figure 2-6 and available field measurements is reasonably good.

As an example of the use of the figure, suppose that Eq. 2-7 has been used to estimate a PM_{10} emission factor of 2.0 kg/VKT. Further, suppose that starting on May 1, the road is treated with 0.25 gal/yd^2 of a (1 part chemical to 5 parts water) solution on the first of each month until October. In this instance, the following average controlled emission factors are found:

Period	Ground inventory, gal/yd^2	Average control efficiency, percent[a]	Average controlled emission factor, kg/VKT
May	0.042	0	2.0
June	0.083	68	0.64
July	0.12	75	0.50
August	0.17	82	0.36
September	0.21	88	0.24

[a] From Figure 2-6; zero efficiency assigned if ground inventory is less than 0.05 gal/yd^2.

A form which could be used as part of a record keeping format is presented in Section 2.2.5.

In formulating dust control plans for chemical dust suppressants, additional topics must be considered. These are briefly discussed below.

Use of paved road controls on chemically treated unpaved roads--Repeated use of chemical dust suppressants tend, over time, to form fairly impervious surfaces on unpaved roads. The resulting surface may admit the use of paved road cleaning techniques (such as flushing, sweeping, etc.) to reduce aggregate loading due to spillage and track-on. A field program showed that treated surfaces could be successfully flushed and vacuumed.[13] PM_{10} control efficiency values of 90% or more (based on the uncontrolled emission factor of the unpaved roads) were found on surfaces that had been last chemically treated 70 days earlier.

The use of paved road techniques for "housekeeping" purposes would appear to have the benefits of both high control (referenced to an uncontrolled unpaved road) and potentially relatively low cost (compared to follow-up chemical applications). Generally, it is recommended that these methods not be employed until the ground inventory exceeds approximately 0.2 gal/yd^2 (0.9 L/m^2). The use of paved road techniques on chemically treated surfaces should, of course, be examined in limited areas prior to implementing a full-scale program.

Minimum reapplication frequency--Because unpaved roads at TSDFs are often used for the movement of materials and are often surrounded by additional unpaved travel areas, spillage and carryout onto the chemically treated road require periodic "housekeeping" activities. In addition, gradual abrasion of the treated surface by traffic will result in loose material on the surface which should be controlled.

It is recommended that at least dilute reapplications be employed every month to control loose surface material unless paved road control techniques are used (as described above). More frequent reapplications would be required if spillage and track-on pose particular problems for a road.

Weather considerations--Roads generally have higher moisture contents during cooler periods due to decreased evaporation. Small increases in surface moisture may result in large increases in control efficiency (as referenced to the dry summertime conditions inherent in the AP-42 unpaved road predictive equation).[3] In addition, application of chemical dust suppressants during the winter may be inadvisable for traffic safety reasons.

Weather-related application schedules should be considered prior to implementing any control program. Responsible parties and regulatory agency personnel should work closely in making this joint determination.

Compared to the other open dust sources discussed in this manual, there is a wealth of cost information available for chemical dust suppressants on unpaved roads. Note that many salt products are delivered and applied by the same truck. For those products, costs are easily obtained by contacting a local distributor.

For other chemicals, identified cost elements include:

Capital: Distributor truck, tanks, pumps, piping

O&M: Chemical suppressants, water, fuel, replacement parts, labor

Many plants contract out application and thus have minimal capital expenditures.

Because each plant faces a unique set of needs, no attempt has been made here to include all possible costs involved in a dust control program. For example, some facilities may be forced to install new storage tanks while others may only need to refurbish unused tanks in the plant. Still others may find it more efficient to retain an outside contractor to store and apply the suppressants.

In order to provide preliminary estimates of costs associated with chemical dust suppressants, the reader may employ the average costs shown in Table 2-10. Delivery and contracted application costs may be estimated by increasing bulk costs by 10% and 15%, respectively.

For treatments at the intensities generally recommended by suppressant vendors, the corresponding unit cost is approximately $5,000 per treatment per mile.[12] At application intensities and dilution ratios common in the iron and steel industry, applied unit costs for chemical suppressants may be estimated as $3,000 per treatment per mile of unpaved road.[13] Note that in the iron and steel industry, lighter application intensities have been found to be more cost-effective over typical time intervals between treatments.

TABLE 2-10. SUMMARY OF UNPAVED ROAD CHEMICAL DUST SUPPRESSANT COSTS

	Chemical suppressant cost, 1985 $/gal	
	Small lot	Bulk
Salts	0.70[a]	0.46[a]
Other	2.60[b]	1.48[c]

[a] Cost includes delivery and application.

[b] FOB costs for 55-gal drums.

[c] FOB; note that at the time this manual was prepared, bulk costs of suppressants are slightly lower than that stated.

Enforcement of a chemical dust control program would ideally consist of two approaches. The first requires the owner to maintain adequate records that would document that a regular program is in place. The second approach involves agency spot checks of controlled roads by taking a material sample from the road. That approach is discussed in detail in Section 2.2.5.

Records must be kept that document the frequency of chemicals applied to unpaved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include the following.

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency.
2. Length of each road and area of each parking lot.
3. Type of chemical applied to each road/area, dilution ratio, application intensity, and planned frequency of application.
4. Provisions for weather.

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.

2. Operator's initials (note that the operator may keep a separate log of whose information is transferred to the environmental staff's data sheets).

3. Start and stop times on a particular segment/parking lot, average speed, number of passes, amount of solution applied.

4. Qualitative description of road surface condition.

General Records to be Kept

1. Equipment maintenance records.

2. Meteorological log (to the extent that weather influences the control program--see above).

3. Any equipment malfunctions or downtime.

In addition to those items related to control application, some of the regulatory formats suggested in Section 2.2.5 require that additional records be kept. These records may include surface material samples or traffic counts, and are discussed below.

2.2.5 Procedures for Compliance Determination

There are numerous regulatory formats possible for unpaved roads. For example, some states have developed opacity measurement techniques by which compliance may be determined. It is important to note that opacity has yet to be related to emission levels from roads. One often-raised question deals with prevailing wind speeds during opacity readings; ambient air concentrations (and hence, opacity levels) tend to be greater under low wind speeds. Consequently, for a road with even a constant emission rate, opacity readings would vary indirectly with wind speed.

Recordkeeping offers another compliance tool for unpaved road dust controls. The level of detail needed varies with the control option employed. Table 2-11 summarizes the level of detail required for the various controls discussed in Section 2.2.4. Eqs. 2-9 and 2-10, together with traffic, application, and meteorological records, would allow one to estimate average control efficiency. Moreover, use of Figure 2-6, together with the form shown as Figure 2-7 allows estimation of chemical suppressant efficiency between applications. Figure 2-8 shows a completed form corresponding to the example in Section 2.2.4.

TABLE 2-11. RECORDKEEPING REQUIREMENTS FOR UNPAVED ROAD CONTROLS

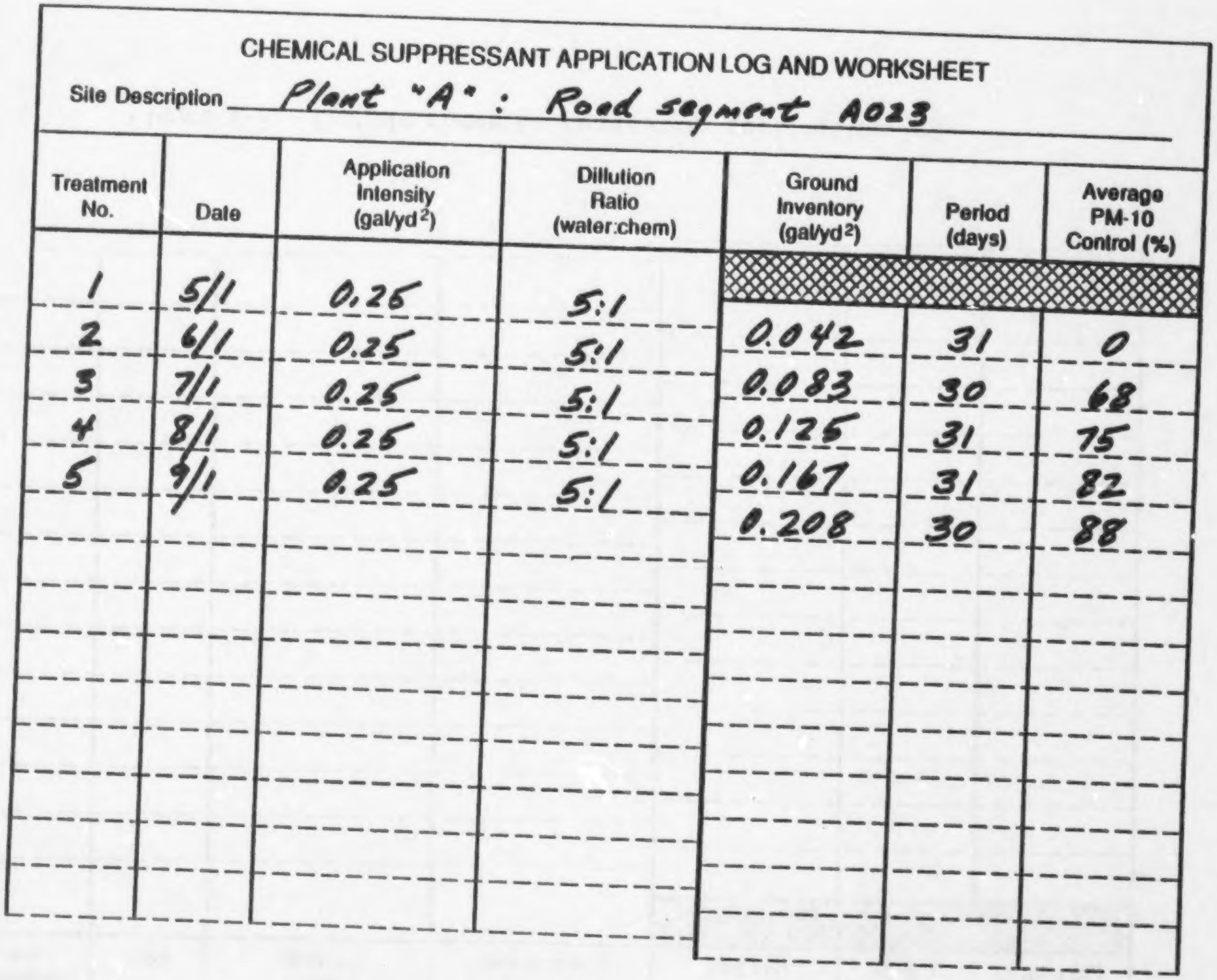
Control	Level of detail	Comments
Paving	Minimal level, starting date of paving, type, etc.	Additional records required if paved road controls employed
Graveling	Minimal level, starting date of graveling, gravel specifications grading/reapplication dates	Before and after measurements of silt content recommended
Watering	Extensive, covering each day/time of application, meteorological conditions, amount of water applied, traffic records	Collection of grab samples for moisture recommended
Chemicals (salts)	Fairly extensive, dates of applications and subsequent waterings	Collection of grab samples for moisture recommended
Chemicals	Moderate, dates and operating parameters for each application	Field samples recommended to bound control efficiency

CHEMICAL SUPPRESSANT APPLICATION LOG AND WORKSHEET

Site Description ____________________

Treatment No.	Date	Application Intensity (gal/yd^2)	Dilution Ratio (water:chem)	Ground Inventory (gal/yd^2)	Period (days)	Average PM-10 Control (%)
				▨	▨	▨

Figure 2-7. Example chemical suppressant application log.



CHEMICAL SUPPRESSANT APPLICATION LOG AND WORKSHEET

Site Description Plant "A" : Road segment A023

Treatment No.	Date	Application Intensity (gal/yd^2)	Dilution Ratio (water:chem)	Ground Inventory (gal/yd^2)	Period (days)	Average PM-10 Control (%)
1	5/1	0.25	5:1	▨	▨	▨
2	6/1	0.25	5:1	0.042	31	0
3	7/1	0.25	5:1	0.083	30	68
4	8/1	0.25	5:1	0.125	31	75
5	9/1	0.25	5:1	0.167	31	82
				0.208	30	88

Figure 2-8. Example completed log.

While recordkeeping affords a convenient method of assessing long-term control performance, it is important that regulatory personnel have "spot-check" compliance tools at their disposal. One such tool was mentioned earlier in connection with Figure 2-5. Rules could be written specifying a minimum surface moisture content (thus, corresponding to a minimum control efficiency) to be maintained on an unpaved surface which is watered or treated with salts. Inspection personnel would then collect grab samples for moisture analysis following the procedures in Appendix D to determine compliance.

For chemically (other than salts) controlled surfaces, it has been found that industrial paved road model (see Table 2-2) tends to *overestimate* the controlled emission factor (and thus, *underestimate* instantaneous control efficiency).[13] In this way, an inspector could collect an unpaved sample with a whisk broom and dust pan, and after laboratory analysis for silt content, have a conservatively low estimate of control efficiency due to the chemical treatment. If a rule is written to maintain a certain level of efficiency, the inspector could then instruct the responsible party to reapply the chemical or use paved road controls (if feasible).

2.3 EXAMPLE CALCULATION

An example application of the emission estimation methods is presented in this section. The example makes use of the hypothetical TSDF shown in Figure 2-9. Summary information on paved roads A and B, and the unpaved road C shown in the figure is given in Table 2-12.

Also, 20 vehicles exit the stabilization unit each day onto paved road B; 15 vehicles per day exit the unit onto the unpaved road C. Road C is 0.3 km long, unpaved access route to the landfill unit with the following characteristics:

- Silt content of 10%
- Average vehicle speed of 30 kph
- Average vehicle wheels is 12

The facility operates 5 d/wk (8 h/d) and 261 d/yr in a location with 100 d/yr of $\geq$ 0.01 in (0.254 mm) of precipitation (on average) and 60 in (1,500 mm) of annual Class A pan evaporation.

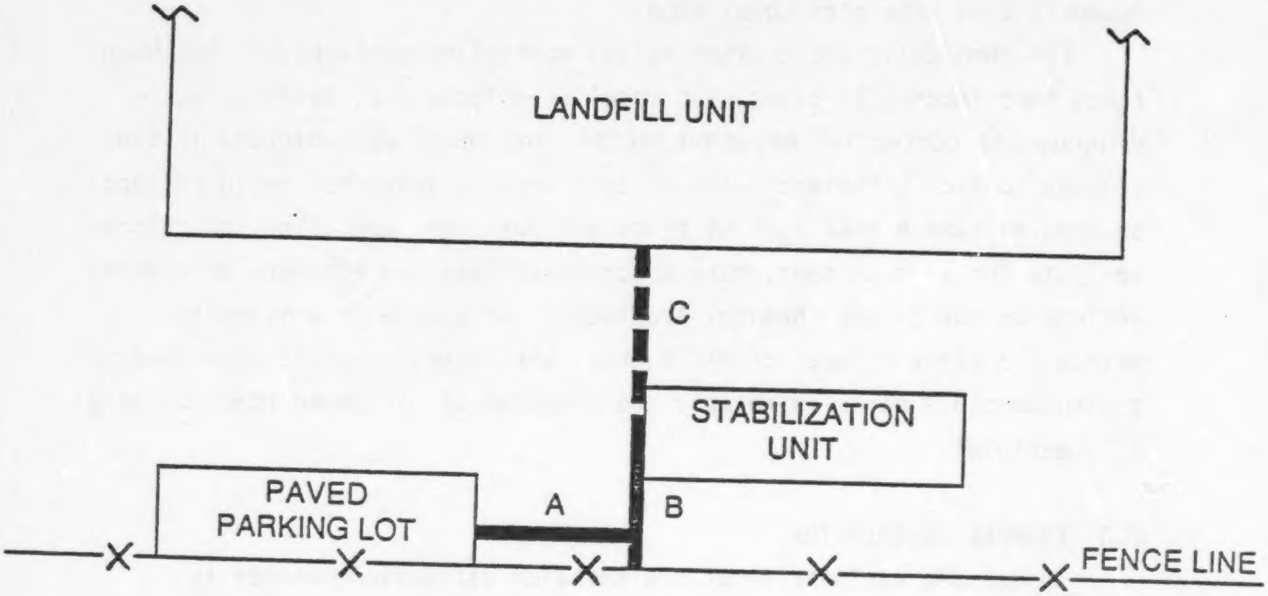

LANDFILL UNIT
C
STABILIZATION UNIT
PAVED PARKING LOT
A
B
FENCE LINE

Figure 2-9. Roads at a hypothetical TSDF.

TABLE 2-12. SUMMARY INFORMATION FOR ROADS A, B, AND C

Road	Length (km)	Vehicle passes per work day[a]	Average vehicle weight (Mg)	Silt loading (g/m^2)
A	0.2	80	2	1.0
B	0.3	100	20	5.0
C	0.3	90	30	N/A[b]

[a] Facility operates 261 days per year.

[b] Road is unpaved; see additional information in Section 2.3.2.

2.3.1 Paved Road Estimates

The "gross" PM_{10} emission factors are estimated using Table 2-2 based on the mean vehicle weights and silt loading given above. Because road A's mean vehicle weight is less than 4 Mg with a silt loading less than 2 g/m^2, a PM_{10} emission factor of

$$2.28(1/0.5)^{0.8}$$

or, 4.0 g/VKT is found. On the other hand, because road B has a mean vehicle weight greater than 6 Mg and a silt loading greater than 2 g/m^2, a PM_{10} emission factor of

$$220(5/12.0)^{0.3}$$

or, 170 g/VKT is found. Corresponding emission rates are:

Road A: 4.0 g/VKT x 80 veh/d x 0.2 km x 261 d/yr, or 17 kg/yr

Road B: 170 g/VKT x 100 veh/d x 0.3 km x 261 d/yr, or 1,300 kg/yr

In order to estimate contaminated emissions from paved road travel using the suggestions in Section 2.1.2.2, it is necessary to first estimate contamination levels in the roadway surface loadings on the roads. In this example, it is assumed that no site-specific sampling and analysis (S&A) program has been undertaken. In addition, it is assumed that because road A is not directly used to access operational areas, that contamination levels for that road's surface loading are negligible. Finally, because road B is used to access both the landfill and stabilization areas, it is conservatively assumed that the long-term loading on the road is composed of material carried out from those units and, as such, has contamination levels identical to travel areas in those units. Here, it is assumed that the Pb concentration of 114 ppm (cf. Table 7-2) is applicable.

With the above assumptions, the estimated Pb emission rate is estimated as

$$\frac{114}{10^6} \times 1{,}300 \text{ kg/yr}$$

or, 0.15 kg/yr. Note that because it is assumed that the long-term loading is due to carryout, additional calculations using Eq. 2-5 are not considered necessary.

Specification of Dust Control Program

Suppose that it is determined that 20% average control of paved road Pb emissions from road B is necessary to achieve a goal (perhaps based on the risk assessment methodology presented in Appendix C). Based on the equation

$$e = 220 \ \frac{sL}{12}^{0.3}$$

presented in Table 2-2, 20% control implies that

$$(1-0.2)(sL_0)^{0.3} = (sL_1)^{0.3}$$

where: sL_0 = uncontrolled silt loading
sL_1 = controlled silt loading

Solving the above equation yields

$$\left(\frac{sL_1}{sL_0}\right) = 0.48 = 1-0.52$$

Thus, a PM_{10} control efficiency of 20% implies that silt loadings must be reduced 52%. Because it is not believed that preventive measures can achieve that silt loading reduction, a mitigative program is envisioned.

The water flushing expressions presented in Table 2-3 indicate that 20% efficiency occurs long after 299 or 365 vehicle passes for water flushing or flushing and broom sweeping, respectively. The models thus suggest that 20% average efficiency is achieved when

$$20 \geq 10,300/V$$

or, $V \leq 515$ vehicle passes for water flushing and

$$20 \geq 17,500/V$$

or, $V \leq 875$ vehicle passes for flushing followed by broom sweeping. Because road B experiences 100 passes per day, the controls would require application roughly every 5 or 9 days, respectively.

2.3.2 Unpaved Road Estimates

Using Eq. 2-7 and the values given above, a PM_{10} emission factor of

$$0.61 \left(\frac{10}{12}\right) \left(\frac{30}{48}\right) \left(\frac{30}{2.7}\right)^{0.7} \left(\frac{12}{4}\right)^{0.5} \frac{365-100}{365}$$

or 2.2 kg/VKT is found. At 90 VP per day and 261 working days per year, an annual emission rate of

$$2.2 \text{ kg/VKT } (90 \text{ veh/d})(261 \text{ d/yr})(0.3 \text{ km})$$

or 15,000 kg/yr is obtained.

Because no on-site sampling and analysis (S&A) program is conducted, assumptions must be made on contamination levels on the road. Because the road is used by landfill-related traffic it is reasonable to expect that a conservatively high estimate may be obtained by setting the α-levels in Eq. 2-8 equal to the mean value measured for landfill surfaces (cf. Table 5-3). Thus, an estimate for the annual Pb emissions is

$$\frac{1,490}{10^6} \times 15,000 \text{ kg/yr}$$

or 22 kg/yr.

Additional Emissions Due to Carryout From Operational Areas

Because material carryout from the stabilization and landfill areas is onto an unpaved road, it is reasonable to expect that "gross" emissions directly related to the carryout is relatively unimportant. The more important concern, of course, is the increase in *contaminated* emissions. Assuming that the carryout emissions from the unpaved road is analogous to that on paved roads, Eq. 2-5 suggested that

$$E^+ = 36 \text{ g/vehicle}$$

for the stabilization unit (N=15 veh/day) and

$$E^+ = 91 \text{ g/vehicle}$$

for the landfill area (N=45 veh/day). Thus, for M=90 veh/day on road C, an annual increase of

$$(36+91) \text{ g/veh} \times 90 \text{ veh/day} \times 261 \text{ d/yr}$$

or 3,000 kg/yr in "gross" emissions is estimated. The increase in contaminated emissions may be estimated using the information presented as footnote ** in Section 2.1.4.1. If it is assumed that the Pb contamination levels in the landfill (Table 5-3) and stabilization units

(Table 7-2) are 1,490 and 114 ppm, respectively, then Pb emissions due to carryout may be estimated as

$$\left(\frac{114}{10^6}\,36 + \frac{1,490}{10^6}\,91\right)\ \text{g/veh} \times 90\ \text{veh/day} \times 261\ \text{day/yr}$$

or 3.3 kg/yr.

In summary, a total of 25 kg/yr of Pb is estimated to be emitted from traffic on road C. Note that in light of assumptions made, this estimate is probably conservatively high.

Specification of Dust Control Program

Assume that 80% average control of emissions is required for road C, and that watering will be used to achieve this control. Based on Eq. 2-9, 80% control requires that

$$80 \geq 100 - \frac{0.8(p)\ (90/8)t}{i}$$

and, using Eq. 2-10, it is seen that

$$\frac{i}{t} \geq \frac{9}{20}\,p = \begin{matrix} 0.13\ \text{L/m}^2\text{/h (annual)} \\ \\ 0.18\ \text{L/m}^2\text{/h (summer)} \end{matrix}$$

Thus, any watering program which applies at least 0.13 (or 0.18) L/m^2 of water for every hour between application will achieve the desired goal. Suitable plans include:

- 0.13(0.18) L/m^2 every hour
- 0.25(0.35) L/m^2 every 2 h
- 0.066(0.88) L/m^2 every 1/2 h

2.4 REFERENCES FOR SECTION 2

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3.0 OPEN WASTE PILES AND STAGING AREAS

Open waste piles constitute a direct source of atmospheric particulate emissions resulting from the action of mechanical disturbance or the forces of wind on the exposed surface. In addition, contamination from the waste pile may spread to surrounding surface materials through successive deposition/ entrainment processes, mechanical track-out by vehicle movement, spillage during pile formation/removal, or migration of leachate from the pile.

3.1 SOURCE DESCRIPTION

Short-term waste piles may be found in several types of TSDF operations. Such piles may be disturbed frequently as part of a particular disposal cycle. At the other extreme, some waste piles may remain substantially intact over periods of months to years. Not unexpectedly, pile size (i.e., volume, height/depth, and exposed surface area) tends to increase with the average waste retention time.[1] For example, based on model waste pile characteristics, a pile with a retention time of several months may have a height up to 4 m and a surface area exceeding 10,000 m^2. On the other hand, piles that are disturbed daily have heights of less than 1 m and surface areas of less than 100 m^2.

Dust emissions occur at several points in the waste retention cycle: during loading of material onto the pile, during disturbances by strong wind currents, and during removal of material from the pile. The movement of trucks and loading equipment in the waste pile area is also a substantial source of dust. The potential for direct emissions from the pile surface increases substantially whenever portions of the pile are disturbed. This tends to occur when material is either added to or removed from the pile or when the pile is otherwise reshaped.

The quantity of dust emissions from waste pile maintenance operations varies with the volume of aggregate passing through the waste retention cycle. Also, emissions depend on three correction parameters that characterize the condition of a particular waste pile: age of the pile, moisture content of the waste, and proportion of aggregate fines. It should be noted that organic chemical constituents of the waste may provide an inherent mitigative effect by binding otherwise suspendable particles to the bulk material.

When finely divided waste (without constituents that provide inherent mitigation) is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents from transfer operations or high winds. As the waste material weathers, however, its potential for dust emissions may be greatly reduced. Moisture from precipitation and condensation causes aggregation and cementation of fines to the surfaces of larger particles.

Field investigations have shown that emissions from certain aggregate storage operations vary in direct proportion to the percentage of silt (particles < 75 µm in diameter) in the aggregate material.[2-9] The silt content is determined by measuring the proportion of dry aggregate material that passes through a 200-mesh screen, using the ASTM-C-136 method. Table 3-1 summarizes measured silt and moisture values for industrial aggregate materials.

3.2 ESTIMATION OF UNCONTROLLED EMISSIONS

Total dust emissions from waste piles are the sum of several distinct source activities within the storage cycle (see Figure 3-1):

1. Loading of waste onto the pile (batch or continuous drop operations).
2. Equipment traffic in waste pile area.
3. Wind erosion of pile surfaces and ground areas around the pile.
4. Loadout of waste for final disposal or for return to the process stream for reclamation (batch or continuous drop operations).

TABLE 3-1. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES

Industry	Material	Silt, percent			Moisture, percent		
		No. of test samples	Range	Mean	No. of test samples	Range	Mean
Wood treatment[a]	Creosote-contaminated soil	4	--	10.2	4	--	11.7
Iron and steel production[b]	Pellet ore	10	1.4-13	4.9	8	0.64-3.5	2.1
	Lump ore	9	2.8-19	9.5	6	1.6-8.1	5.4
	Coal	7	2-7.7	5	6	2.8-11	4.8
	Slag	3	3-7.3	5.3	3	0.25-2.2	0.92
	Flue dust	2	14-23	18.0	0	NA	NA
	Coke breeze	1		5.4	1		6.4
	Blended ore	1		15.0	1		6.6
	Sinter	1		0.7	0	NA	NA
	Limestone	1		0.4	0	NA	NA
Stone quarrying and processing[c]	Crushed limestone	2	1.3-1.9	1.6	2	0.3-1.1	0.7
Taconite mining and processing[d]	Pellets	9	2.2-5.4	3.4	7	0.05-2.3	0.96
	Tailings	2	NA	11.0	1		0.35
Western surface coal mining[e]	Coal	15	3.4-16	6.2	7	2.8-20	6.9
	Overburden	15	3.8-15	7.5	0	NA	NA
	Exposed ground	3	5.1-21	15.0	3	0.8-6.4	3.4

[a] Reference 2.

[b] References 4 through 7. NA = Not applicable.

[c] Reference 3.

[d] Reference 8.

[e] Reference 9.

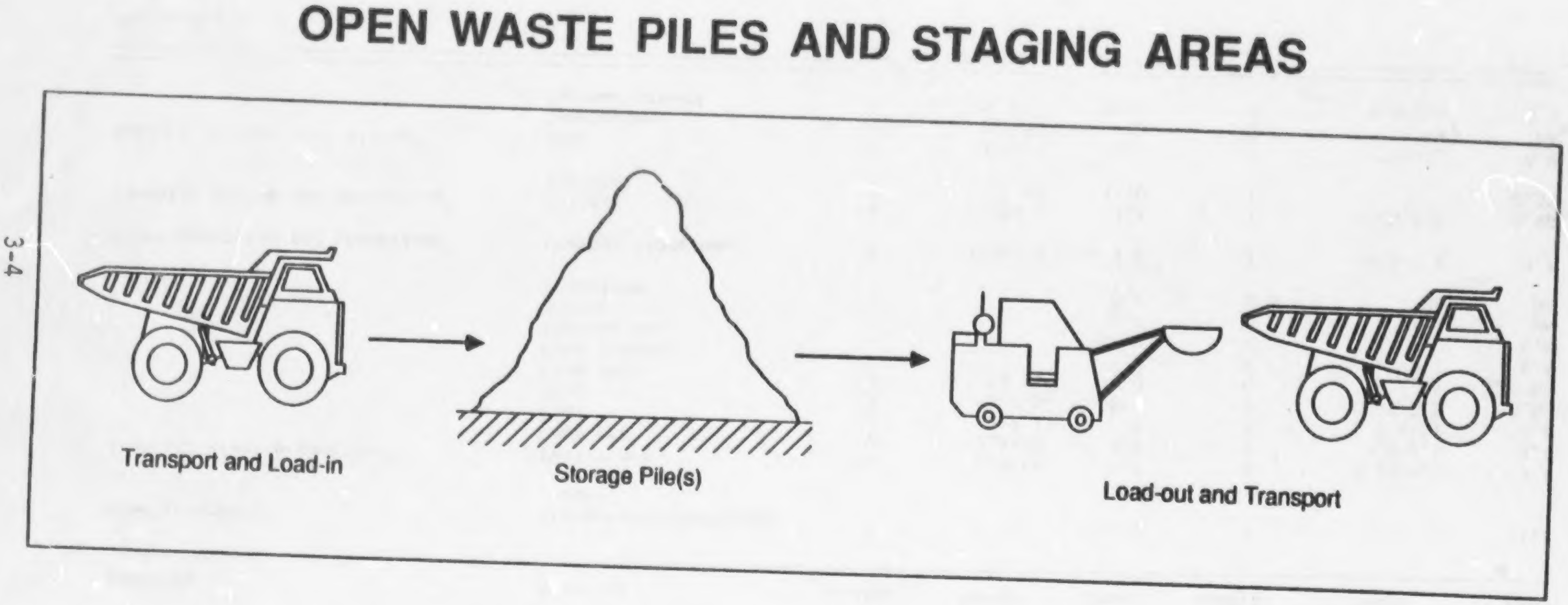

OPEN WASTE PILES AND STAGING AREAS
Transport and Load-in
Storage Pile(s)
Load-out and Transport

Figure 3-1. Open waste piles and staging areas.

Items 1 and 4 (pile formation and removal) fall under the general category of materials handling as discussed below. Equipment traffic in the waste pile area occurs primarily in association with pile formation and removal.

3.2.1 Materials Handling

Adding waste material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

The following equation is recommended for estimating emissions from transfer operations (batch or continuous drop):

$$e = k(0.0016)\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (kg/Mg)}$$

(3-1)

$$e = k(0.0016)\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (lb/ton)}$$

where: e = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed, m/s (mph)
M = material moisture content, %

The particle size multiplier k varies with aerodynamic particle diameter as shown below:

Aerodynamic Particle Size Multiplier, k

<30 μm	<15 μm	<10 μm	<5 μm	<2.5 μm
0.74	0.48	0.35	0.20	0.11

For emissions from equipment traffic (trucks, front-end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 2.0). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

3.2.2 Wind Erosion

Dust emissions may be generated by wind erosion of open waste piles and exposed areas within a disposal facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 cm in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 m/s (11 mph) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

3.2.2.1 Emissions and Correction Parameters. If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7-10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mi contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries.[10] The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_o} \quad (z > z_o) \tag{3-2}$$

where: u = wind speed, cm/s
u^* = friction velocity, cm/s
z = height above test surface, cm
z_o = roughness height, cm
0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_o) is a measure of the roughness of the exposed surface as determined from the y-intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 3-2 for a roughness height of 0.1 cm. The roughness height (z_o) is needed to convert the friction velocity to the equivalent wind speed at the typical weather station sensor height of 7 to 10 m above the surface.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

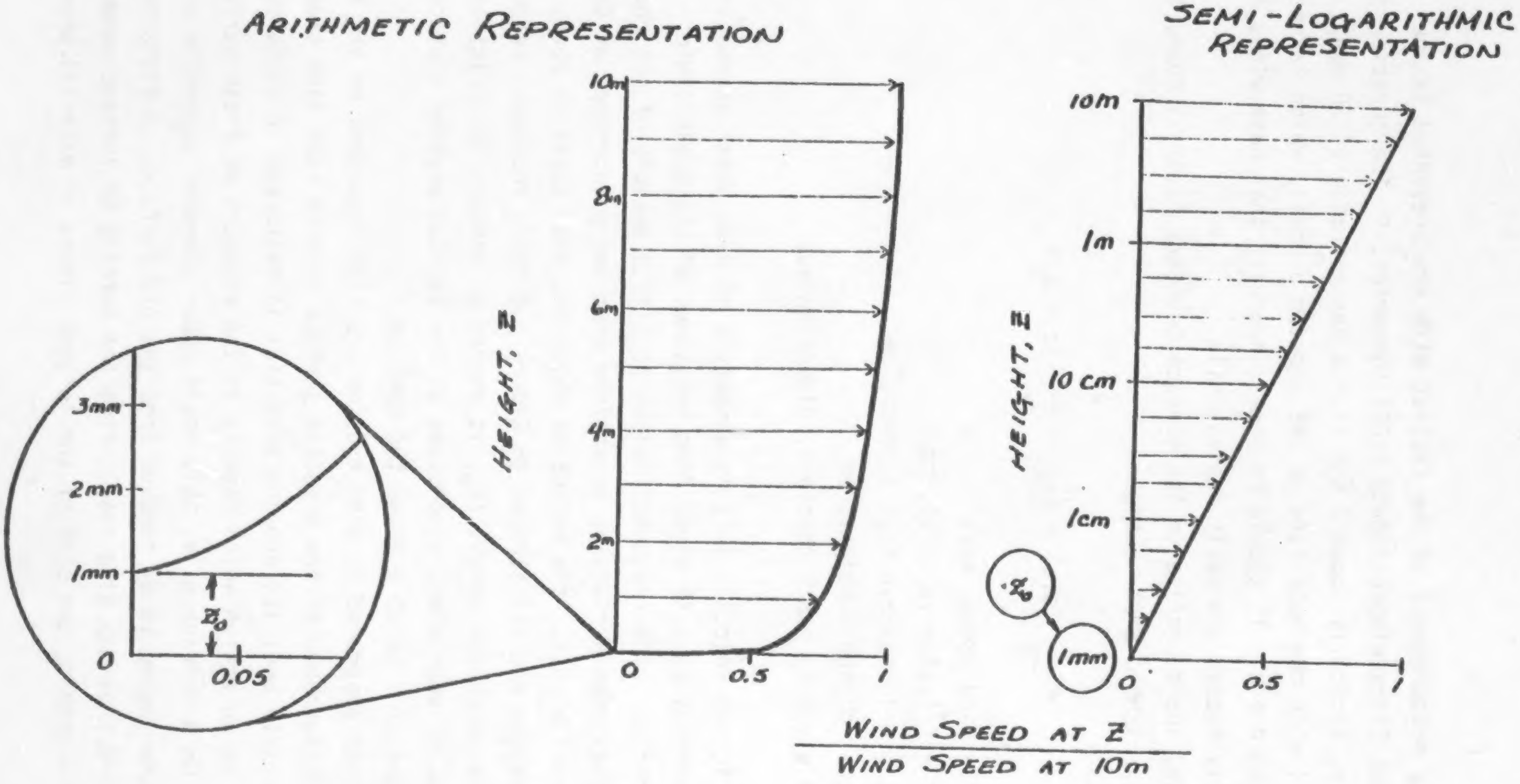


Figure 3-2. Illustration of logarithmic velocity profile.

3.2.2.2 Predictive Emission Factor Equation[11]. The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m²-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \tag{3-3}$$

where: k = particle size multiplier

N = number of disturbances per year

P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the i-th period between disturbances, g/m²

The particle size multiplier (k) for Equation 3-3 varies with aerodynamic particle size, as follows:

Aerodynamic Particle Size Multipliers for Equation 3-3

<30 µm	<15 µm	<10 µm	<2.5 µm
1.0	0.6	0.5	0.2

This distribution of particle size within the < 30 µm fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see AP-42 Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365/yr, and for a surface disturbance once every 6 mo, N = 2/yr.

The erosion potential function for a dry, exposed surface has the following form:

$$P = 58\,(u^* - u_t^*)^2 + 25\,(u^* - u_t^*)$$
$$P = 0 \text{ for } u^* \le u_t^* \qquad (3\text{-}4)$$

where: u^* = friction velocity (m/s)

u_t^* = threshold friction velocity (m/s)

Table 3-2 presents the erosion potential function in matrix form. Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 3-3 and 3-4 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil (adapted from a laboratory procedure published by W. S. Chepil[12]) can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts. This procedure is specified in Section 4.2.1. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, following a relationship derived by Gillette,[13] as shown in Figure 3-3.

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel.[13-16] These values are presented in Tables 3-3 and 3-4 for industrial aggregates and Arizona sites. Figure 3-4 depicts these data graphically.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.[10] These summaries report actual fastest mile values for each day of a given month.

TABLE 3-2. EROSION POTENTIAL FUNCTION

	P (g/m²)											
u_*, m/s $u_t^* =$	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
0.2	0	0	0	0	0	0	0	0	0	0	0	0
0.4	7	0	0	0	0	0	0	0	0	0	0	0
0.6	19	7	0	0	0	0	0	0	0	0	0	0
0.8	36	19	7	0	0	0	0	0	0	0	0	0
1.0	57	36	19	7	0	0	0	0	0	0	0	0
1.2	83	57	36	19	7	0	0	0	0	0	0	0
1.4	114	83	57	36	19	7	0	0	0	0	0	0
1.6	149	114	83	57	36	19	7	0	0	0	0	0
1.8	188	149	114	83	57	36	19	7	0	0	0	0
2.0	233	188	149	114	83	57	36	19	7	0	0	0
2.2	282	233	188	149	114	83	57	36	19	7	0	0
2.4	336	282	233	188	149	114	83	57	36	19	7	0
2.6	394	336	282	233	188	149	114	83	57	36	19	7
2.8	457	394	336	282	233	188	149	114	83	57	36	19
3.0	525	457	394	336	282	233	188	149	114	83	57	36

TABLE 3-3. THRESHOLD FRICTION VELOCITIES--INDUSTRIAL AGGREGATES

Material	Threshold friction velocity, m/s	Roughness height, cm	Threshold wind velocity at 10 m (m/s)		Ref.
			z_o = actual	z_o = 0.5 cm	
Overburden[a]	1.02	0.3	21	19	9
Scoria (roadbed material)[a]	1.33	0.3	27	25	9
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	9
Uncrusted coal pile[a]	1.12	0.3	23	21	9
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	9
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	15

[a] Western surface coal mine.

[b] Lightly crusted.

[c] Eastern power plant.

TABLE 3-4. THRESHOLD FRICTION VELOCITIES--ARIZONA SITES[16]

Location	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)
Mesa - Agricultural site	0.57	0.0331	16
Glendale - Construction site	0.53	0.0301	15
Maricopa - Agricultural site	0.58	0.1255	14
Yuma - Disturbed desert	0.32	0.0731	8
Yuma - Agricultural site	0.58	0.0224	17
Algodones - Dune flats	0.62	0.0166	18
Yuma - Scrub desert	0.39	0.0163	11
Santa Cruz River, Tucson	0.18	0.0204	5
Tucson - Construction site	0.25	0.0181	7
Ajo - Mine tailings	0.23	0.0176	7
Hayden - Mine tailings	0.17	0.0141	5
Salt River, Mesa	0.22	0.0100	7
Casa Grande - Abandoned agricultural land	0.25	0.0067	8

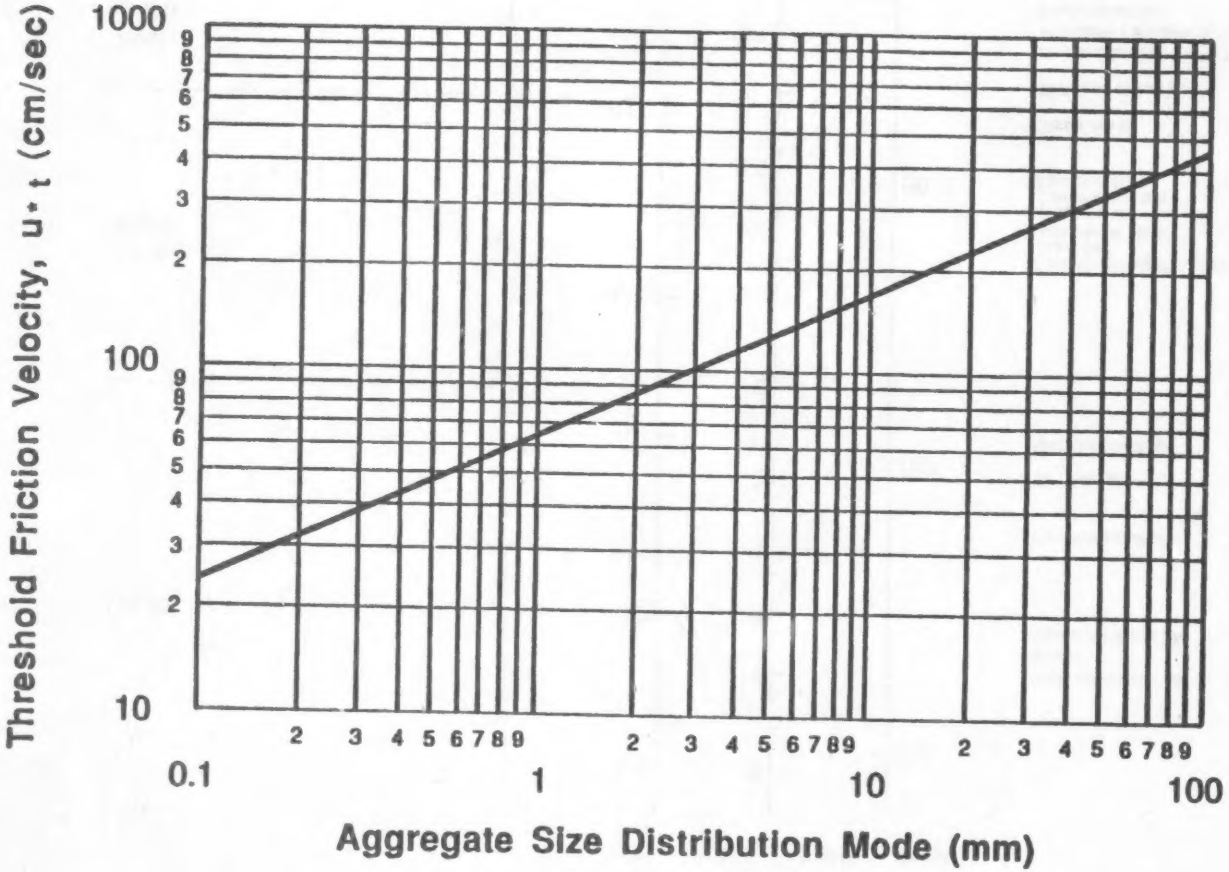


Figure 3-3. Relationship of threshold friction velocity to size distribution mode.

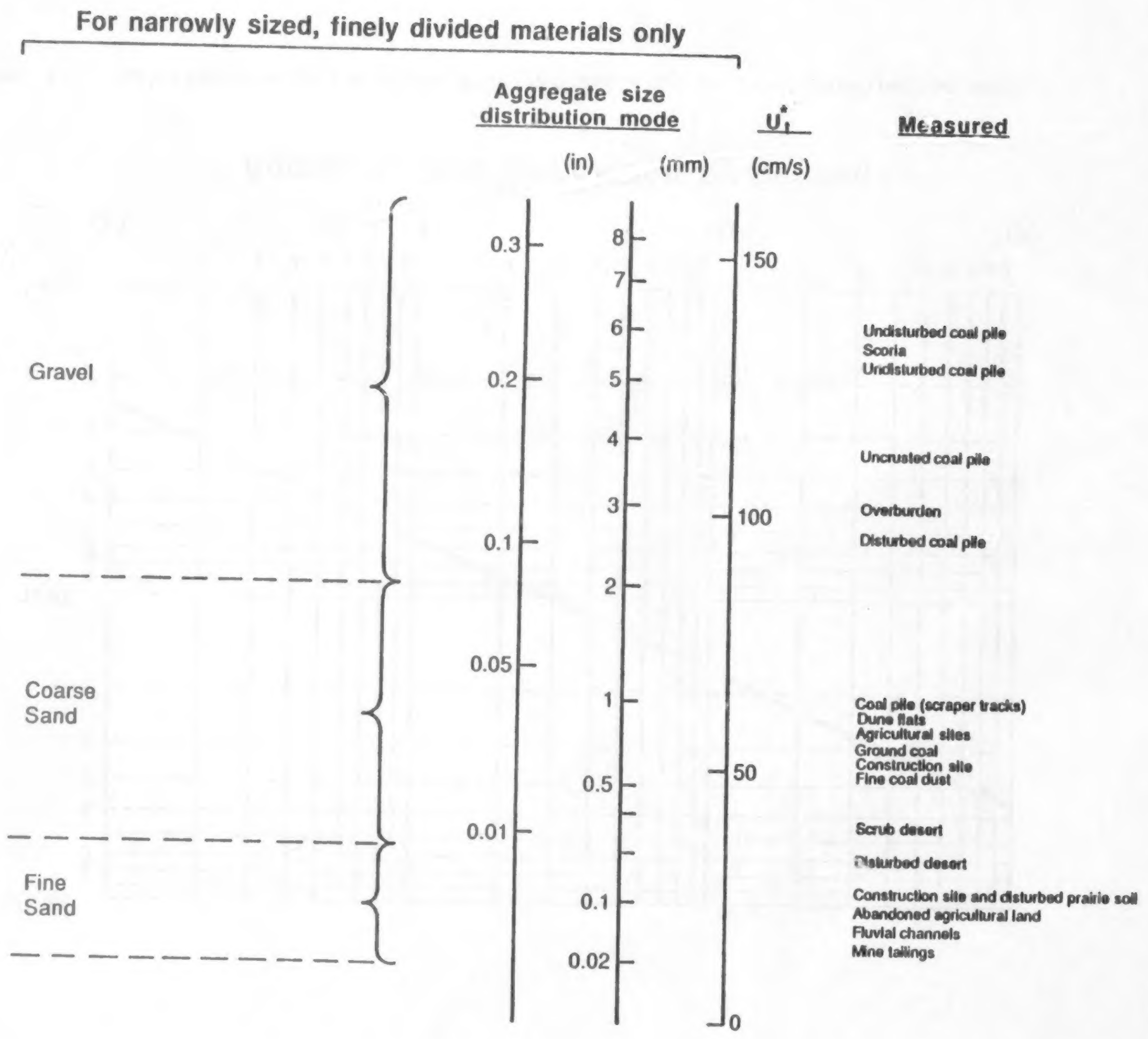


Figure 3-4. Scale of threshold friction velocities.

Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 17, and should be corrected to a 10 m reference height using Equation 3-2.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\ u^+_{10} \qquad (3\text{-}5)$$

where: u^* = friction velocity (m/s)

u^+_{10} = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 3-5 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

If the pile significantly penetrates the surface wind layer (i.e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flat-top, 37 degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.[14] The results are shown in Figure 3-5 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_0) of 0.5 cm. The measured surface winds correspond to a height of 25 cm above the surface. The area fraction within each contour pair is specified in Table 3-5.

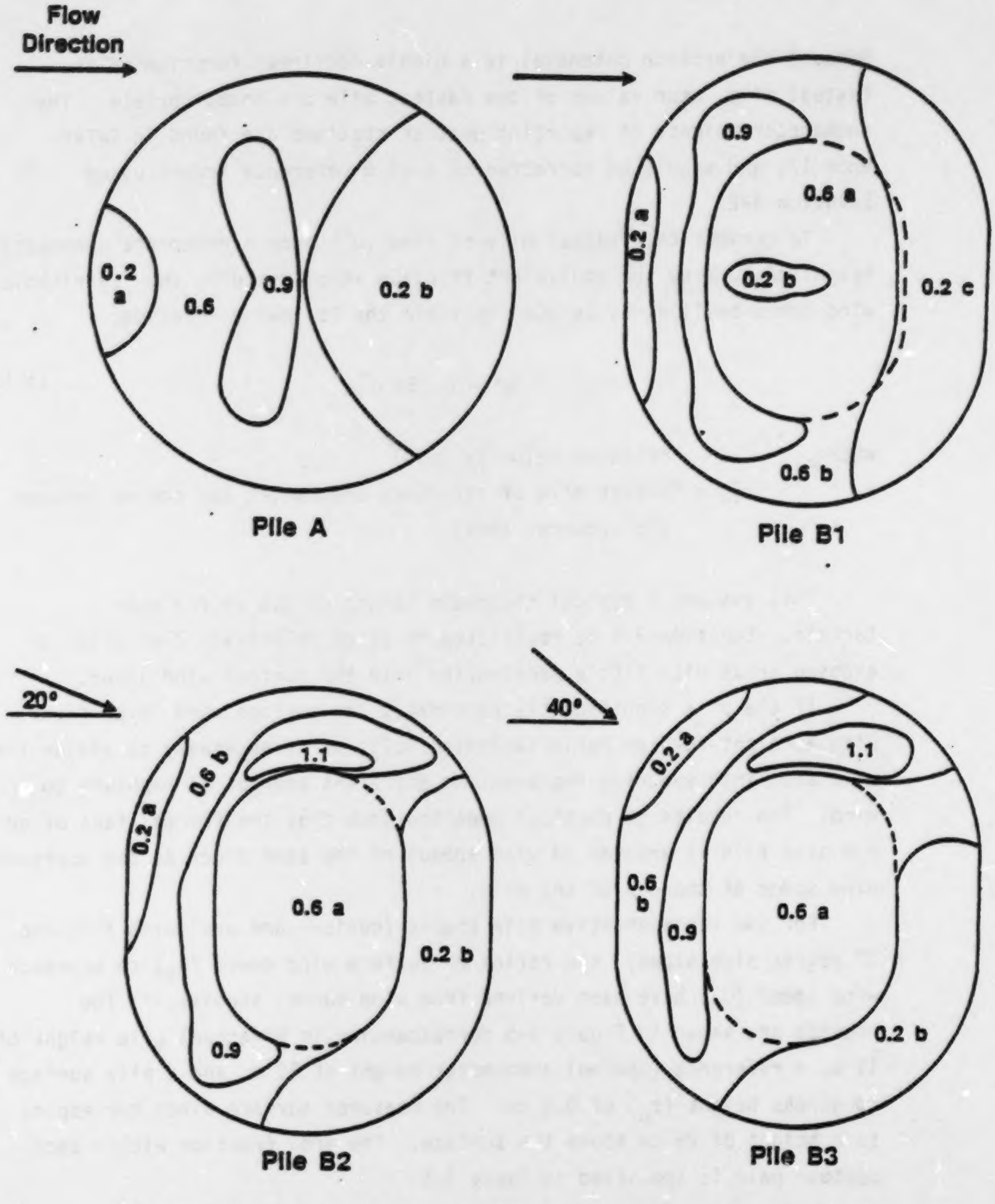

Flow Direction
0.2 a
0.6
0.9
0.2 b
Pile A
0.9
0.6 a
0.2 a
0.2 b
0.2 c
0.6 b
Pile B1
20°
1.1
0.6 b
0.2 a
0.6 a
0.2 b
0.9
Pile B2
40°
0.2 a
1.1
0.6 b
0.6 a
0.9
0.2 b
Pile B3

Figure 3-5. Contours of normalized surface wind speeds, u_s/u_r.

TABLE 3-5. SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r

Pile subarea	Percent of pile surface area (Figure 3-3)			
	Pile A	Pile B1	Pile B2	Pile B3
0.2a	5	5	3	3
0.2b	35	2	28	25
0.2c	-	29	-	-
0.6a	48	26	29	28
0.6b	-	24	22	26
0.9	12	14	15	14
1.1	-	-	3	4

The profiles of u_s/u_r in Figure 3-5 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u^+_{10}) using a variation of Equation 3-2, as follows:

$$u^+_{10} = u^+ \frac{\ln (10/0.005)}{\ln (z/0.005)} \tag{3-6}$$

   where a typical roughness height of 0.5 cm (0.005 m) has been assumed. If a site specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 3-5 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u^+_s), i.e.,

$$u^+_s = \left(\frac{u_s}{u_r}\right) u^+_{10} \tag{3-7}$$

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 4-2 to calculate the equivalent friction velocity (u^*), as follows:

$$u^* = \frac{0.4\, u^+_s}{\ln \frac{25}{0.5}} = 0.10\, u^+_s \tag{3-8}$$

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Tables 3-3 and 3-4 or use Figure 3-3 to determine the mode of the aggregate size distribution).
2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u^+_{10}) using Equation 3-6.
4. Convert fastest mile values (u^+_{10}) to equivalent friction velocities (u^*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 3-5, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 3-7 and 3-8.
5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i.e., within the isopleth values of u_s/u_r in Figure 3-5 and Table 3-5) and determine the size of each subarea.
6. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3-4 and the emission factor using Equation 3-3.
7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-h emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 min, which corresponds roughly to the half-life for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process which offset this apparent conservatism:

1. The fastest mile event contains peak winds which substantially exceed the mean value for the event.
2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed which contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

3.2.3 Wind Erosion of Continuously Active Piles

For emissions from wind erosion of active storage piles, the following total suspended particulate (TSP) emission factor equation is recommended:

$$E = 1.9 \left(\frac{s}{1.5}\right) \left(\frac{365-p}{235}\right) \left(\frac{f}{15}\right) \text{ (kg/d/hectare)}$$

$$E = 1.7 \left(\frac{s}{1.5}\right) \left(\frac{365-p}{235}\right) \left(\frac{f}{15}\right) \text{ (lb/d/acre)} \qquad (3\text{-}9)$$

where: E = total suspended particulate emission factor
s = silt content of aggregate, %
p = number of days with $\geq$0.25 mm (0.01 in.) of precipitation per year
f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s (12 mph) at the mean pile height

The PM_{10} fraction of TSP is estimated to be 0.5, consistent with the PM_{10}/TSP ratios for materials handling (Section 3.2.1) and wind erosion (Section 3.2.2).

The coefficient in Equation (3-9) is taken from Reference 3, based on sampling of emissions from a sand and gravel storage pile area during periods when transfer and maintenance equipment was not operating. The factor from Reference 3, expressed in mass per unit area per day, is more reliable than the factor expressed in mass per unit mass of material placed in storage, for reasons stated in that report. Note that the coefficient has been halved to adjust for the estimate that the wind speed through the emission layer at the test site was one half of the value measured above the top of the piles. The other terms in this equation were added to correct for silt, precipitation, and frequency of high winds, as discussed in Reference 2.

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling (batch and continuous drop) operations may be calculated by substituting into Equation (3-1) appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 h. The treatment of dry conditions for vehicle traffic (Section 2.0) and for wind erosion (Equation 3-9), centering around parameter p, follows the methodology described in Section 2.0. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

3.2.4 Level of Contamination

Although published data on waste pile contamination levels are sparse, the data presented in Reference 2 suggest several points that may be useful in specifying the level of contamination (α) for permitted waste piles. These include:

- Source-specific S&A probably will be required to reliably characterize α levels for organic compounds. If a source-specific S&A plan is being developed (see Appendix D for generic procedures), the data in Reference 2 indicate that organic compounds with lower vapor pressures tend to be found more often than compounds with high vapor pressures (i.e., volatile compounds). As a result then the S&A plan should be directed toward organic compounds with relatively low vapor pressures (< 10 mm Hg).

- As an alternative to source-specific S&A, a "worst-case" scenario could be developed based on the ranges of available data. For example, this could be accomplished by taking the maximum values (upper end of the range) and applying a "safety factor" of 5 or 10. In other words, multiply the upper end values by 5 or 10 as a conservatively high estimate of α.

3.3 DEMONSTRATED CONTROL TECHNIQUES

The control techniques applicable to storage piles fall into distinct categories as related to materials handling operations (including traffic around piles) and wind erosion. In both cases, the control can be achieved by (a) source extent reduction, (b) source improvement related to work practices and transfer equipment (load-in and load-out operations), and (c) surface treatment. These control options are summarized in Table 3-6. The efficiency of these controls ties back to the emission factor relationships presented earlier in this section.

In most cases, good work practices which confine freshly exposed material provide substantial opportunities for emission reduction without the need for investment in a control application program. This statement applies to areas around the pile as well as the pile itself. In particular, spillage of material caused by pile load-out and maintenance equipment can add a large source component associated with traffic-entrained dust. Emission inventory calculations show, in fact, that the traffic dust component may easily dominate emissions from transfer of material and wind erosion. The prevention of spillage and subsequent spreading of material by vehicle tracking is essential to cost-effective emission control. If spillage cannot be prevented because of the need for intense use of mobile equipment in the waste pile area, then regular cleanup should be employed as a necessary mitigative measure.

The evaluation of preventative methods which change the properties or exposure of transfer streams or surface material are discussed in the following section.

TABLE 3-6. CONTROL TECHNIQUES FOR STORAGE PILES

Material handling	
Source extent reduction	Mass transfer reduction
Source improvement	Drop height reduction Wind sheltering Moisture retention
Surface treatment	Wet suppression
Wind erosion	
Source extent reduction	Disturbed area reduction Disturbance frequency reduction Spillage cleanup
Source improvement	Spillage reduction Wind exposure reduction
Surface treatment	Wet suppression Chemical stabilization

3.4 CONTROL PERFORMANCE ESTIMATION

Preventive methods for control of emissions from waste piles include chemical stabilization, enclosures, and wet suppression. Physical stabilization by covering the exposed surface with less erodible aggregate material and/or vegetative stabilization are seldom practical control methods for waste piles, unless piles are to remain in place for long periods of time.

To test the effectiveness of chemical stabilization controls for wind erosion of aggregate storage piles and tailings piles, wind tunnel measurements have been performed. Although most of this work has been carried out in laboratory wind tunnels, portable wind tunnels have been used in the field on storage piles and tailings piles.[18,19] Laboratory wind tunnels have also been used with physical models to measure the effectiveness of wind screens in reducing surface wind velocity.[14]

3.4.1 Chemical Stabilization

A portable wind tunnel has been used to measure the control of coal pile wind erosion emissions by a 17% solution of Coherex® in water applied at an intensity of 3.4 L/m² (0.74 gal/yd²), and a 2.8% solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 6.8 L/m² (1.5 gal/yd²).[18] The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 days before the test, under a wind of 15.0 mi/s (33.8 mph) at 15.2 cm (6 in.) above the ground, was 89.6% for TP and approximately 62% for IP and FP. The control efficiency of the latex binder on a low volatility coking coal is shown in Figure 3-6.

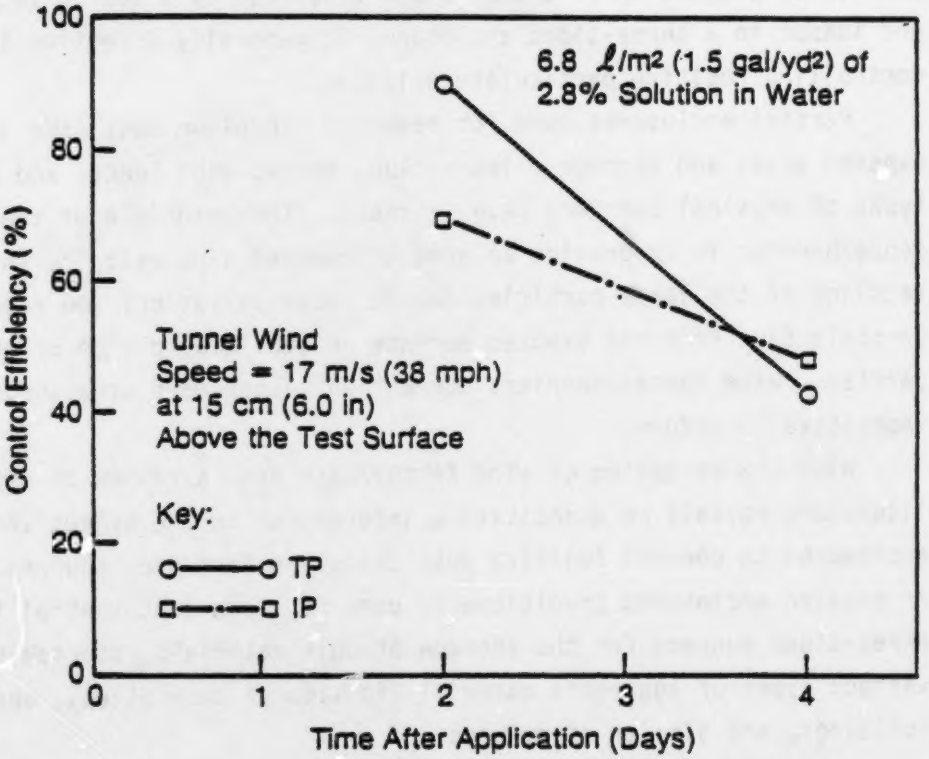


Figure 3-6. Decay in control efficiency of latex binder applied to coal storage piles.[18]

Cost elements for chemical stabilization are presented in Table 3-7. The cost of a system for application of surface crusting chemicals to storage piles is $18,400 for the initial capital cost and $0.006 to $0.011/ft^2 for annual operating expenses based on April 1985 dollars.[20] Tables 3-8 and 3-9 provide recordkeeping forms for application of chemical dust suppressants.

3.4.2 Enclosures

Enclosures are an effective means by which to control fugitive particulate emissions from open dust sources. Enclosures can either fully or partially enclose the source. Included in the category of partial enclosures are porous wind screens or barriers. Practically any means that reduces wind entrainment of particles from a dust-producing surface or dispersion of a dust plume generated by a source (e.g., front-end loader in a three-sided enclosure) is generally effective in controlling fugitive particulate emissions.

Partial enclosures used for reducing windblown dust from large exposed areas and storage piles include porous wind fences and similar types of physical barriers (e.g., trees). The principle of the wind fence/barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier. Wind fences/barriers can either be man-made structures or vegetative in nature.

With the exception of wind fences/barriers, a review of available literature reveals no quantitative information on the effectiveness of enclosures to control fugitive dust emissions from open sources. Types of passive enclosures traditionally used for open dust control include three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material (in lieu of open piles), open-ended buildings, and similar structures.

A number of studies have attempted to determine the effectiveness of wind fences/barriers for the control of windblown dust under field conditions. Several of these studies have shown both a significant decrease in wind velocity as well as an increase in sand dune growth on the lee side of the fence.[21-24]

TABLE 3-7. CAPITAL AND O&M ITEMS FOR CHEMICAL STABILIZATION OF WASTE PILES

Capital equipment

- Storage equipment
  - Tanks
  - Railcars
  - Pumps
  - Piping

- Application equipment
  - Trucks
  - Spray system
  - Piping (including winterizing)

O&M expenditures

- Utility or fuel costs
  - Water
  - Electricity
  - Gasoline or diesel fuel

- Supplies
  - Chemicals
  - Repair parts

- Labor
  - Application time
  - Road conditioning
  - System maintenance

TABLE 3-8. TYPICAL FORM FOR RECORDING CHEMICAL DUST SUPPRESSANT CONTROL PARAMETERS

Date	Time	Type of chemical	Dilution ratio	Application intensity, gal/yd^2	Area(s) treated	Equipment used	Operator initials	Comments

TABLE 3-9. TYPICAL FORM FOR RECORDING DELIVERY OF CHEMICAL DUST SUPPRESSANTS

Date	Time	Chemical delivered	Quantity delivered	Delivery agent	Facility destination[a]	Comments

[a] Denote whether suppressant will be applied immediately upon receipt or placed in storage.

A 1988 laboratory wind tunnel study[14] of windbreak effectiveness for coal storage piles showed area-averaged wind speed reductions of ~ 50% to 70% for a 50% porosity windbreak with height equal to the pile height and length equal to the pile base. The windbreak was located three pile heights upwind from the base of the pile. This study also suggested "that fugitive dust emissions on the top of the pile may be controlled locally through the use of a windbreak at the top of the pile."

Based on the 1.3 power given in Equation (3-1), mean wind speed reductions of ~ 50% to 70% would correspond to ~ 60% to 80% control of material handling PM_{10} emissions. Estimation of the wind erosion control efficiency requires source-specific evaluation because of the dependence of erosion potential on u_t^* and u^* (for both controlled and uncontrolled conditions) as shown in Equation (3-4).

This same laboratory study[14] showed that a storage pile may itself serve as a windbreak by reducing wind speed on the leeward face (Figure 3-5). The degree of wind sheltering and associated wind erosion emission reduction is dependent on the shape of the pile and on the approach angle of the wind to an elongated pile.

One of the real advantages of wind fences for the control of PM_{10} involves the low capital and operating costs.[21,23] These involve the following basic elements:

- Capital equipment
    - Fence material and supports
    - Mounting hardware
- Operating and maintenance expenditures
    - Replacement fence material and hardware
    - Maintenance labor

The following cost estimates (in 1980 dollars) were developed for wind screens applied to aggregate storage piles:[26]

- Artificial wind guards
    - Initial capital cost = \$12,000 to \$61,000

Due to the lack of quantitative data on costs associated with wind screens, it is recommended that local vendors be contacted to obtain more detailed data for capital and operating expenses. Also, since wind fences and screens are relatively "low tech" controls, it may be possible for the site operator to construct the necessary equipment using site personnel with less expense.

As with other options mentioned above, the main regulatory approach for wind fences and screens would involve recordkeeping by the site operator. Parameters to be specified in the dust control plan and routinely recorded are:

General Information

1. Locations of all materials storage and handling operations to be controlled with wind fences referenced on a plot plan available to the site operator and regulatory personnel
2. Physical dimensions of each source to be controlled and configuration of each fence or screen to be installed
3. Physical characteristics of material to be handled or stored for each operation to be controlled by fence(s) or screen(s)
4. Applicable prevailing meteorological data (e.g., wind speed and direction) for site on an annual basis

Specific Operational Records

1. Date of installation of wind fence or screen and initials of installer
2. Location of installation relative to source and prevailing winds
3. Type of material being handled and stored and physical dimensions of source controlled
4. Date of removal of wind fence or screen and initials of personnel involved

General Records to be Kept

1. Fence or screen maintenance record
2. Log of meteorological conditions for each day of site operation

3.4.3 Wet Suppression Systems

Fugitive emissions from aggregate materials handling systems are frequently controlled by wet suppression systems. However, use of water-based dust suppression systems may result in unacceptable increases in contaminated leachate production. Thus, before instituting a watering program, the facility must demonstrate that addition of water to the waste pile area does not produce undesirable impacts on ground and surface water quality.

Wet suppression systems use liquid sprays or foam to suppress the formation of airborne dust. The primary control mechanisms are those that prevent emissions through agglomerate formation by combining small dust particles with larger aggregate or with liquid droplets. The key factors that affect the degree of agglomeration and, hence, the performance of the system are the coverage of the material by the liquid and the ability of the liquid to "wet" small particles. This section addresses two types of wet suppression systems--liquid sprays which use water or water/surfactant mixtures as the wetting agent and systems which supply foams as the wetting agent.

Liquid spray wet suppression systems can be used to control dust emissions from materials handling at conveyor transfer points. The wetting agent can be water or a combination of water and a chemical surfactant. This surfactant, or surface active agent, reduces the surface tension of the water. As a result, the quantity of liquid needed to achieve good control is reduced. For systems using water only, addition of surfactant can reduce the quantity of water necessary to achieve a good control by a ratio of 4:1 or more.[27,28]

The design specifications for wet suppression systems are generally based on the experience of the design engineer rather than on established design equations or handbook calculations. Some general design guidelines that have been reported in the literature as successful are listed below:

1. A variety of nozzle types have been used on wet suppression systems, but recent data suggest that hollow cone nozzles produce the greatest control while minimizing clogging.[29]
2. Optimal droplet size for surface impaction and fine particle agglomeration is about 500 μm; finer droplets are affected by drift and surface tension and appear to be less effective.[30]
3. Application of water sprays to the underside of a conveyor belt improves the performance of wet suppression systems at belt-to-belt transfer points.[31]

Micron-sized foam application is an alternative to water spray systems. The primary advantage of foam systems is that they provide equivalent control at lower moisture addition rates than spray systems.[31] However, the foam system is more costly and requires the use of extra materials and equipment. The foam system also achieves control primarily through the wetting and agglomeration of fine particles. The following guidelines to achieve good particle agglomeration have been suggested:[32]

1. The foam can be made to contact the particulate material by any means. High velocity impact or other brute force means are not required.
2. The foam should be distributed throughout the product material. Inject the foam into free-falling material rather than cover the product with foam.
3. The amount applied should allow all of the foam to dissipate. The presence of foam with the product indicates that either too much foam has been used or it has not been adequately dispersed within the material.

Available data for both water spray and foam wet suppression systems are presented in Tables 3-10 and 3-11, respectively. The data primarily include estimates of control efficiency based on concentrations of total particulate or respirable dust in the workplace atmosphere. Some data on mass emissions reduction are also presented. The data should be viewed with caution in that test data ratings are generally low and only minimal data on process or control system parameters are presented.

The data in Tables 3-10 and 3-11 do indicate that a wide range of efficiencies can be obtained from wet suppression systems. For conveyor transfer stations, liquid spray systems had efficiencies ranging from 42% to 75%, while foam systems had efficiencies ranging from 0% to 92%. The data are not sufficient to develop relationships between control or process parameters and control efficiencies. However, the following observations relative to the data in Tables 3-10 and 3-11 are noteworthy:

1. The quantity of foam applied to a system does have an impact on system performance. On grizzly transfer points, foam rates of 7.5 ft^3 to 10.5 ft^3 of foam per ton of sand produced increasing control efficiencies ranging from 68% to 98%.[33] Foam rates below 5 ft^3 per ton produced no measurable control.

TABLE 3-10. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WATER SPRAYS

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Control efficiency percent[b]
25	Chain feeder to belt transfer	Coal	3 ft drop, 8 tons coal per load	8 sprays, 2.5 gal/min, above belt only	Personnel samplers, Type 1 test scheme	10	RP 56 TP 59
				8 sprays, 2.5 gal/min and one one spray on underside of belt	Personnel samplers, Type 1 test scheme	4	RP 81 TP 87
	Belt-to-belt transfer	Coal	Not specified	8 sprays, 2.5 gal/min above belt only[c]	Personnel samplers, Type 1 test scheme	10	RP 53
				8 sprays, 2.5 gal/min and one one spray on underside of belt[c]	Personnel samplers, Type 1 test scheme	4	RP 42
27	Grizzly transfer to the bucket elevator	Run of mill sand	Not specified	Liquid volume 757 ml	Personnel samplers, Type 1 test scheme	NA	RP 46
				Liquid volume 1,324 ml	Personnel samplers, Type 1 test scheme	NA	RP 58
				Liquid volume 1,324 ml[d]	Personnel samplers, Type 1 test scheme	NA	RP 54
				Liquid volume 1,324 ml[e]	Personnel samplers, Type 1 test scheme	NA	RP 54
28	Conveyor transport and transfer	Coal	2 belts 0.91 m and 1.07 m widths, ~500 m length	3 spray bars/belt, underside of tail pulley, 5-10 cc H_2O/s per bar, Delevan "Fanjet" sprays	Personnel samplers, Type 1 test scheme[f]	NA	RP-65-75

[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] TP = Total particulate; RP = respirable particulate.

[c] Control applied at a point five transfers upstream.

[d] Water+1.5 percent surfactant.

[e] Water+2.5 percent surfactant.

[f] Individual test values not specified; no airflow data or QA/QC data.

TABLE 3-11. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR FOAM SUPPRESSION SYSTEMS

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Control efficiency percent[b]
27	Belt-to-belt transfer	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	RP 20[c]
	Belt-to-bin transfer	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	RP 33[c]
	Bulk loadout	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	RP 65[c]
	Screw-to-belt transfer	Cleaned run-of-mine sand	174 tons/h, sand temp. ~190°F	Moisture = 0.25 percent	Grav/RAM samplers, Type 1 scheme	4	RP 10[c]
	Bucket elevator discharge	Cleaned run-of-mind sand	179 tons/h, sand temp. ~190°F	Moisture = 0.18 percent	RAM/personnel samplers, Type 1 test scheme	5	RP 8[c]
	Belt-to-belt transfer	Cleaned run-of-mine sand	193 tons/h, sand temp. ~190°F	Moisture = 0.18 percent	RAM/personnel samplers, Type 1 test scheme	8	RP 7[c]
	Feeder bar discharge	Cleaned run-of-mine sand	191 tons/h, sand temp. ~190°F	Moisture = 0.19 percent	RAM/personnel samplers, Type 1 test scheme	6	RP 2[c]
	Grizzley transfer to bucket elevator	Dried run of mine sand	Not specified	Foam rate = 10.5 ft^3/ton sand Liquid rate = 0.38 gal/min	Personnel samplers, Type 1 test scheme	2	RP 92
				Foam rate = 8.2 ft^3/ton sand Liquid rate = 0.34 gal/min	Personnel samplers, Type 1 test scheme	1	RP 74
				Foam rate = 7.5 ft^3/ton sand Liquid rate = 0.20 gal/min	Personnel samplers, Type 1 test scheme	1	RP 68
25	Chain feeder to belt transfer	Coal	3-ft drop, 8 tons coal per load	50 psi H_2O, 2.5 percent reagent[c], four nozzles 15 to 20 ft^3 foam applied[d]	Personnel samplers, Type 1 test scheme	9	RP 96 TP 92
	Belt-to-belt transfer	Coal	Not specified	50 psi H_2O, 2.5 percent reagent[c], four nozzles 15 to 20 ft^3 foam applied[d]			RP 71

(continued)

TABLE 3-11. (continued)

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Control efficiency percent[b]
27	Grizzley	Dried run-of-mine sand	Not specified	Foam rate = 4.8 ft^3/ton sand Liquid rate = 0.18 gal/min	Personnel samplers, Type 1 test scheme	2	RP 0
				Foam rate = 2.6 ft^3/ton sand Liquid rate = 0.13 gal/min	Personnel samplers, Type 1 test scheme	NA	RP 0
				Liquid volume 1,420 ml	Personnel samplers, Type 1 test scheme	NA	RP 91
				Liquid volume 1,330 ml	Personnel samplers, Type 1 test scheme	NA	RP 73
				Liquid volume 764 ml	Personnel samplers, Type 1 test scheme	NA	RP 68

[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.

[b] RP = respirable particulate.

[c] Efficiency based on concentrations only.

[d] Control applied at a point five transfers upstream.

2. Material temperature has an impact on foam performance. At one plant where sand was being transferred, control efficiencies ranged from 20% to 65% when 120°F sand was handled. When sand temperature was increased to 190°F, all control efficiencies were below 10%.[33]

3. Data at one plant suggest that underside belt sprays increase control efficiencies for respirable dust (56% to 81%).[31]

4. When spray systems and foam systems are used to apply equivalent moisture concentrations, foam systems appear to provide greater control.[33] On a grizzly feed to a crusher, equivalent foam and spray applications provided 68% and 46% control efficiency, respectively. Capital and O&M cost elements for wet suppression are shown in Table 3-12.

In estimating the wind erosion control effectiveness of wet suppression, it can be assumed that emissions are inversely proportional to the square of the surface moisture content. The emission/moisture dependence is embedded in the agricultural wind erosion equation. It also appears in the observed relationship between the rate of emissions from an unpaved road and the surface moisture content.

In addition, a relationship between surface moisture content and daily moisture addition has been developed from field studies of storage piles exposed to natural precipitation. The results of that research are illustrated in the example problem to be presented at the end of this section.

Costs associated with wet suppression systems include the following basic elements:

- Capital equipment
    - Spray nozzles or other distribution equipment
    - Supply pumps and plumbing (plus weatherization)
    - Water filters and flow control equipment
    - Tanker truck (if used)
- Operating and maintenance expenditures
    - Water and chemicals
    - Replacement parts for nozzles, truck, etc.
    - Operating labor
    - Maintenance labor

TABLE 3-12. WET SUPPRESSION SYSTEM CAPITAL AND O&M COST ELEMENTS

Capital equipment

- Water spray system
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units
- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity
- Supplies
  - Surfactant
  - Screens
- Labor
  - Maintenance
  - Operation

Reference 6 estimates the following costs (in 1985 dollars):

- Regular watering of storage piles
  - -- Initial capital cost = $18,400 per system
- Watering of exposed areas
  - -- Initial capital cost = $1,053 per acre
  - -- Annual operating cost = $25 to $67 per acre

The costs associated with a stationary wet suppression system using chemical surfactants for the unloading of limestone from trucks at aggregate processing plants (in 1980 dollars) have been estimated at:

capital = $72,000; annual = $26,000.

Typical costs for wet suppression of materials transfer operations are listed in Table 3-13.

TABLE 3-13. TYPICAL COSTS FOR WET SUPPRESSION OF MATERIAL TRANSFER POINTS

Source method	Initial cost, April 1985 dollars[a]	Unit operating cost, April 1985 dollars[a]
Railcar unloading station (foam spray)	48,700	NR
Railcar unloading station (charged fog)	168,000[b]	NR
Conveyor transfer point (foam spray)	23,700	0.02 to 0.05/ton material treated
Conveyor transfer point (charged fog)	19,800[c]	NR

Source: Reference 20. NR = not reported.

[a] January 1980 costs updated to April 1985 cost by Chemical Engineering Index. Factor = 1.315.

[b] Based on use of 16 large devices at $10,500 each.

[c] Based on use of three small devices at $6,600 each.

As with watering of unpaved surfaces, enforcement of a wet suppression control program would consist of two complementary approaches. The first would be record keeping to document that the program is being implemented and the other would be spot-checks and grab sampling. Both were discussed previously above.

Records must be kept that document the control plan and its implementation. Pertinent parameters to be specified in a plan and to be regularly recorded include:

General Information

1. Locations of all materials storage and handling operations referenced on plot plan of the site available to the site operator and regulatory personnel
2. Materials delivery or transport flow sheet which indicates the type of material, its handling and storage, size and composition of storage piles, etc.
3. The method and application intensity of water, etc., to be applied to the various materials and frequency of application, if not continuous
4. Dilution ratio for chemicals added to water supply, if any
5. Complete specifications of equipment used to handle the various materials and for wet suppression
6. Source of water and chemical(s), if used

Specific Operational Records

1. Date of operation and operator's initials
2. Start and stop time of wet suppression equipment
3. Location of wet suppression equipment
4. Type of material being handled and number of loads (or other measure of throughput) loaded/unloaded between start and stop time (if material is being pushed, estimate the volume or weight)
5. Start and stop times for tank filling

General Records

1. Equipment maintenance records
2. Meteorological log of general conditions
3. Records of equipment malfunctions and downtime

3.5 PROCEDURES FOR COMPLIANCE DETERMINATION

There are several possible regulatory formats for control of dust emissions from waste piles. Commonly used opacity standards at the property line are applicable as are opacity standards at the point of emissions for continuous drop of material on to a pile by a stacker.

For wet suppression and chemical stabilization, suitable recordkeeping forms, such as those presented in Tables 3-8 and 3-9, would provide evidence of control plan implementation. In addition, simple measurements of moisture level in transferred material or of the crust strength of the chemically treated surface could be used to verify compliance. If the crust is more than 0.6 cm thick and not easily crumbled between the fingers, then the surface may be considered nonerodible. In addition, the loading as well as the texture of material deposited around the pile could be used to check whether good work practices are being employed relative to pile reclamation and maintenance operations. The suitability of these measurements of surrogate parameters for source emissions stems from the emission factor models which relate the parameters directly to emission rate. Potential regulatory formats for control of waste pile emissions are listed in Table 3-14.

3.6 EXAMPLE CALCULATION

Source Description

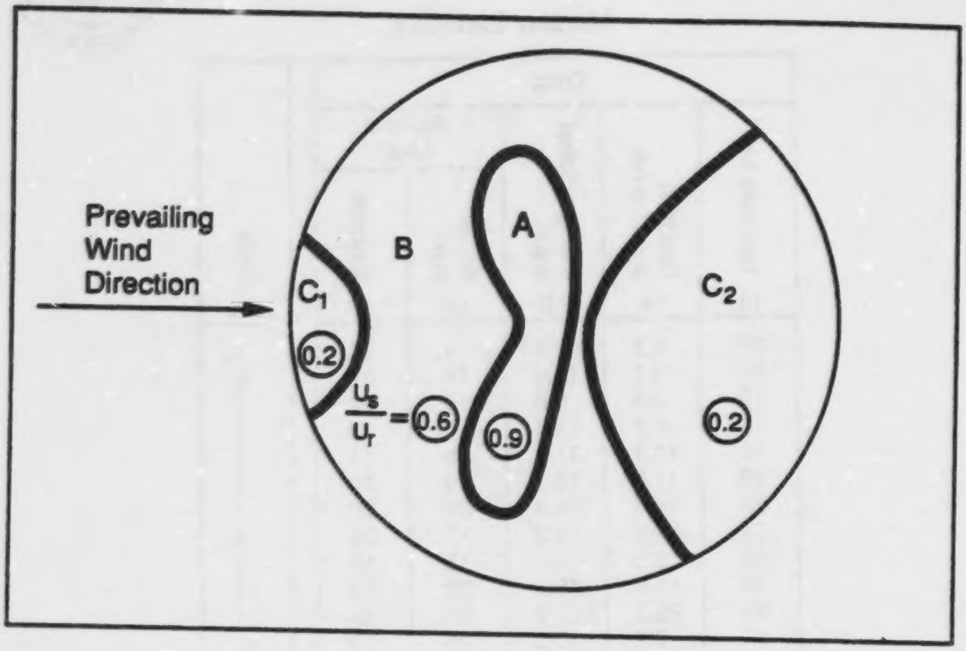
- Conically shaped pile (dry, finely divided material)
- Pile height of 11 m; 29.2 m base diameter; 838 m^2 surface area
- Pile formation followed by 30-d exposure period before removal (Figure 3-7)
- LCD as shown in Figure 3-8 for a typical month
- Contamination level, α = 12,000 ppm Pb

Calculation of Uncontrolled Emissions

Step 1: A composite sample of approximately 0.5 L of waste material was obtained by collecting nearly equal amounts from six areas of the pile surface. This sample was hand-sieved according to the procedures shown in Figure 3-9.

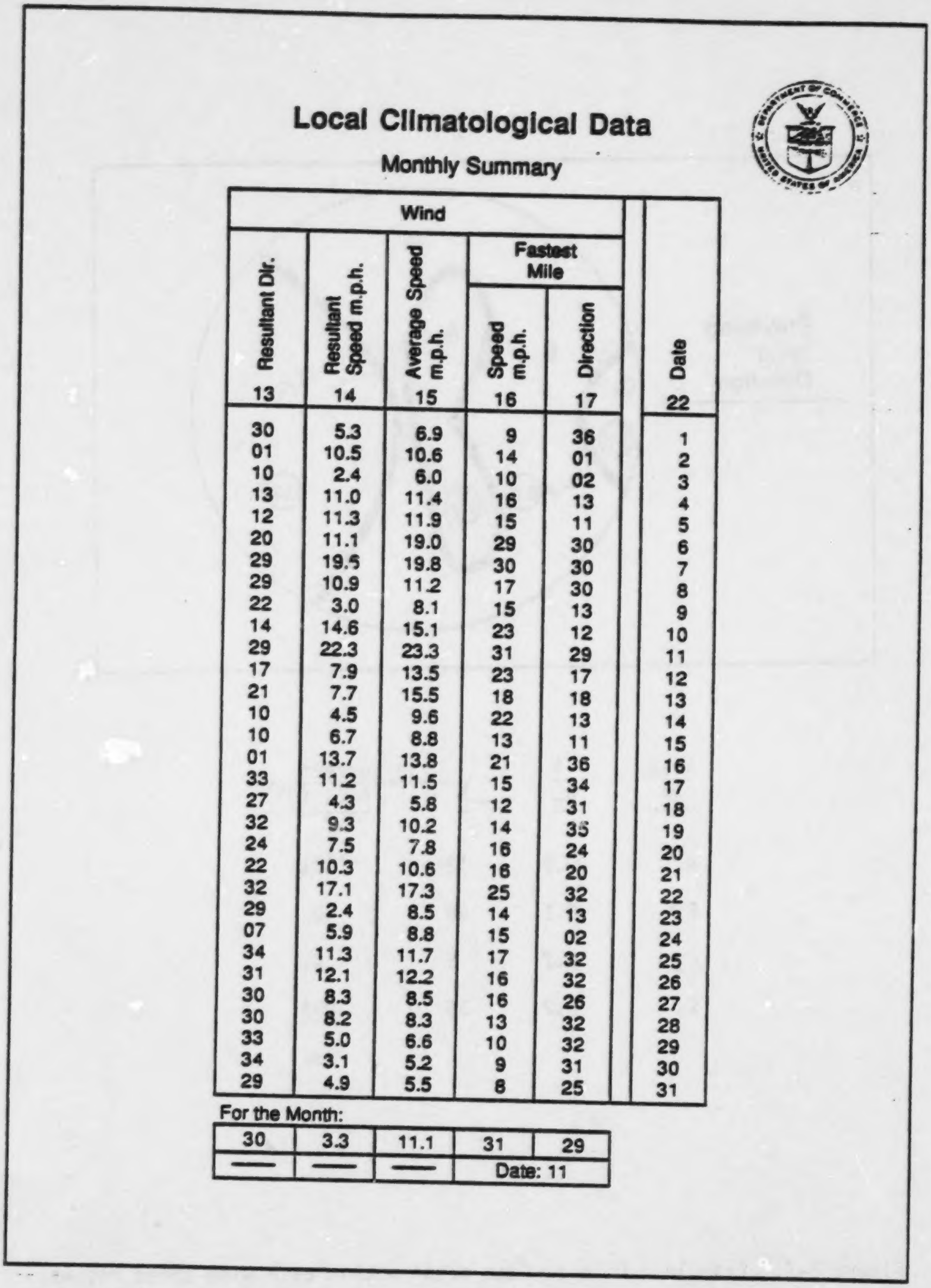
TABLE 3-14. COMPLIANCE DETERMINATION FOR WASTE PILES

Source	Emission surrogate	Control measure	Field audit parameter
Waste handling	% VE at property line or at source; PM_{10}/TSP concentration at property line	Wind sheltering Wet suppression	Surface wind speed Waste moisture content
Wind erosion	Threshold friction velocity; % VE at property line or at source; PM_{10}/TSP concentration at property line	Chemical stabilization Wind sheltering Wet suppression	Surface crust and texture Wind speed Surface moisture content


Prevailing
Wind
Direction
B
A
C_1
C_2
0.2
$\frac{u_s}{u_r}$ = 0.6
0.9
0.2

Area ID	$\frac{u_s}{u_r}$	Pile Surface %	Pile Surface Area (m^2)
A	0.9	12	101
B	0.6	48	402
C_1	0.2	5	42
C_2	0.2	35	293
			838

Figure 3-7. Example. Pile surface areas within each wind speed regime.



Local Climatological Data

Monthly Summary

Wind						
Resultant Dir. 13	Resultant Speed m.p.h. 14	Average Speed m.p.h. 15	Fastest Mile			Date 22
			Speed m.p.h. 16	Direction 17		
30	5.3	6.9	9	36		1
01	10.5	10.6	14	01		2
10	2.4	6.0	10	02		3
13	11.0	11.4	16	13		4
12	11.3	11.9	15	11		5
20	11.1	19.0	29	30		6
29	19.5	19.8	30	30		7
29	10.9	11.2	17	30		8
22	3.0	8.1	15	13		9
14	14.6	15.1	23	12		10
29	22.3	23.3	31	29		11
17	7.9	13.5	23	17		12
21	7.7	15.5	18	18		13
10	4.5	9.6	22	13		14
10	6.7	8.8	13	11		15
01	13.7	13.8	21	36		16
33	11.2	11.5	15	34		17
27	4.3	5.8	12	31		18
32	9.3	10.2	14	35		19
24	7.5	7.8	16	24		20
22	10.3	10.6	16	20		21
32	17.1	17.3	25	32		22
29	2.4	8.5	14	13		23
07	5.9	8.8	15	02		24
34	11.3	11.7	17	32		25
31	12.1	12.2	16	32		26
30	8.3	8.5	16	26		27
30	8.2	8.3	13	32		28
33	5.0	6.6	10	32		29
34	3.1	5.2	9	31		30
29	4.9	5.5	8	25		31

For the Month:

30	3.3	11.1	31	29
——	——	——	Date: 11	

Figure 3-8. Daily fastest miles of wind for periods of interest.

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY*

1. PREPARE A NEST OF SIEVES WITH THE FOLLOWING OPENINGS: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. PLACE A COLLECTOR PAN BELOW THE BOTTOM SIEVE (0.25-mm OPENING).
2. COLLECT A SAMPLE REPRESENTING THE SURFACE LAYER OF LOOSE PARTICLES (APPROXIMATELY 1 cm IN DEPTH FOR AN UNCRUSTED SURFACE), REMOVING ANY ROCKS LARGER THAN ABOUT 1 cm IN AVERAGE PHYSICAL DIAMETER. THE AREA TO BE SAMPLED SHOULD NOT BE LESS THAN 30 cm x 30 cm.
3. POUR THE SAMPLE INTO THE TOP SIEVE (4-mm OPENING), AND PLACE A LID ON THE TOP.
4. ROTATE THE COVERED SIEVE/PAN UNIT BY HAND USING BROAD SWEEPING ARM MOTIONS IN THE HORIZONAL PLANE. COMPLETE 20 ROTATIONS AT A SPEED JUST NECESSARY TO ACHIEVE SOME RELATIVE HORIZONTAL MOTION BETWEEN THE SIEVE AND THE PARTICLES.
5. INSPECT THE RELATIVE QUANTITIES OF CATCH WITHIN EACH SIEVE AND DETERMINE WHERE THE MODE IN THE AGGREGATE SIZE DISTRIBUTION LIES, I.E., BETWEEN THE OPENING SIZE OF THE SIEVE WITH THE LARGEST CATCH AND THE OPENING SIZE OF THE NEXT LARGEST SIEVE.

---

*ADAPTED FROM A LABORATORY PROCEDURE PUBLISHED BY W. S. CHEPIL (1952).[12]

Figure 3-9

Visual inspection of the quantities retained on each sieve showed that the largest amounts were contained on the 1 mm and 2 mm sieves. Therefore, a particle size mode of 1.5 mm was assumed. This size mode corresponds to a threshold friction velocity of 75 cm/sec as obtained from Figure 3-3.

Step 2: The entire pile surface is disturbed only once (i.e., at the beginning of the 1-mo exposure period). This corresponds to a value of N = 1/yr.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 3-8 shows a representative set of values (for a 1-mo period) that are assumed to be applicable to the geographic area of the pile location. The highest value for the 1-mo period is 31 mph (13.9 m/s). In this example, the anemometer height is 7 m, so that a height correction to 10 m is needed for the fastest mile values.

From Equation (3-6)

$$u_{10}^{+} = u_{7}^{+} \frac{\ln (10/0.005)}{\ln (7/0.005)}$$

$$u_{10}^{+} = 1.05\, u_{7}^{+}$$

$$= 1.05(13.9) = 14.6 \text{ m/s}$$

Step 4: The next step is to convert the fastest mile value for the 1-mo period into the equivalent friction velocity for each surface wind regime (i.e., u_s/u_r ratio) of the pile, using Equations 3-7 and 3-8. Figure 3-7 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 m). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 3-15. As indicated, the friction velocity exceeds the threshold value of 0.75 m/s within the u_s/u_r = 0.9 regime and the 0.6 regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations.

Steps 6 and 7: The final set of calculations (shown in Table 3-15) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation (3-4).

For example, the calculation for the 0.9 regime is:

$$\begin{aligned} P_2 &= 58(1.31 - 0.75)^2 + 25(1.31 - 0.75) \\ &= 32.2 \text{ g/m}^2 \end{aligned}$$

The PM_{10} emissions generated by the fastest mile event are found as the product of the PM_{10} multiplier (k = 0.5), the erosion potential (P), and the affected area of the pile (A).

TABLE 3-15. EXAMPLE CALCULATION OF UNCONTROLLED PM_{10} EMISSIONS[a]

	u_s/u_r	u^* (m/s)	$u^*-u_t^*$ (m/s)	P (g/m²)	Pile surface A (m²)	Pile surface kPA (kg)
A	0.9	1.31	0.56	32.2	101	1.626
B	0.6	0.88	0.13	4.2	402	0.844
C_1	0.2	0.29	-	0	42	0
C_2	0.2	0.29	-	0	293	0

[a] Where $u_t^* = 0.75$ m/s and k = 0.5 for PM_{10}.

As shown in Table 3-15, the results of these calculations indicate an uncontrolled PM_{10} emission total of 2.47 kg. Multiplying by the contaminant fraction gives 2.47 kg x 12,000/1,000,000 = 29.6 g of Pb emissions for the 1-mo exposure period.

Target Control Efficiency: 60%

Method of Control: Application of a latex binder to the pile surface immediately after pile formation.

Demonstration of Control Program Adequacy: Uncontrolled PM_{10} wind erosion emissions, E_u, from the storage pile were shown to be 2.47 kg for the month. To achieve a control efficiency of 60%, calculate the controlled emissions, E_c, using the following relationship.

$$E_c = E_u (1 - 0.60)$$

$$= 2.47(1 - 0.6)$$

$$= 1.00 \text{ kg}$$

The desired control efficiency of 60% may be achieved, in effect, by increasing the threshold friction velocity through the application of a latex binder. A field study of the effectiveness of various chemical dust suppressants on finely divided tailings material indicates that a threshold velocity of approximately 1.06 m/s over a period of 1 month can be achieved by a single application of latex binder. In this study, Nalco 655 or 656 (full strength) was applied at an application intensity of 0.25 gal/yd^2.[19]

As indicated in Table 3-16, the effect of the latex binder application in reducing the threshold friction velocity to 1.06 m/s is to reduce the PM_{10} emission rate to a value of 1.00 kg resulting from wind erosion over the 1-mo exposure period. This yields the desired control efficiency of 60%, i.e., the PM_{10} emissions are reduced to 40% of the uncontrolled value of 2.47 kg (Table 3-15). Contaminated PM_{10} would be reduced correspondingly to 1.00 kg x 12,000/1,000,000 = 12 g Pb emissions.

TABLE 3-16. EXAMPLE CALCULATION OF CONTROLLED PM_{10} EMISSIONS[a]

u_s/u_r	u^* (m/s)	$u^*-u_t^*$ (m/s)	P (g/m²)	Pile surface A (m²)	 kPA (kg)
0.2	0.29	-	0	335	0
0.6	0.88	-	0	402	0
0.9	1.31	0.25	9.88	101	0.997
				Total PM_{10}	1.00 kg

[a]Where $u_t^* = 1.06$ m/s and k = 0.5 for PM_{10}.

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4.0 DRY SURFACE IMPOUNDMENTS

Dry surface impoundments are sources of PM_{10} emissions resulting from wind erosion of exposed surface material or excavation of waste residue from the surface. A hazardous waste lagoon may approach dry surface conditions if the impounded liquid is pumped out or evaporated. Unless the lagoon has reached the end of its usefulness, it will be refilled with additional liquid waste material. Otherwise, the removal and disposal of dry contaminated bottom material must be dealt with as a source of PM_{10} emissions associated with redesign or closure of the facility.

At some waste disposal facilities an array of open surface impoundments may be used to store and/or treat oily waste for an extended period. In these cases, wind erosion tends to be less of a problem because of the inherent binding effect of organic constituents which remains until the residue is disturbed. On the other hand, the removal of waste residue is an integral part of the waste treatment cycle so that it occurs with regularity. Here again, however, some inherent mitigation of the residue removal process may be expected.

4.1 SOURCE DESCRIPTION

The removal of residual material from a dry surface impoundment typically involves a scraping/dozing operation. The residual material may be (a) added directly to existing impoundment berms or (b) if a freeboard problem in the impoundment is anticipated, the material may be loaded into dump trucks and transferred to an on-site landfill. The subject of dust control in landfill operations is addressed in Section 5.0. Dust generating activities associated with the removal of waste residue from dry surface impoundments are depicted in Figure 4-1.

The uppermost layer of the low permeability soils (e.g., compacted clay), which typically are used to line a dry surface impoundment,

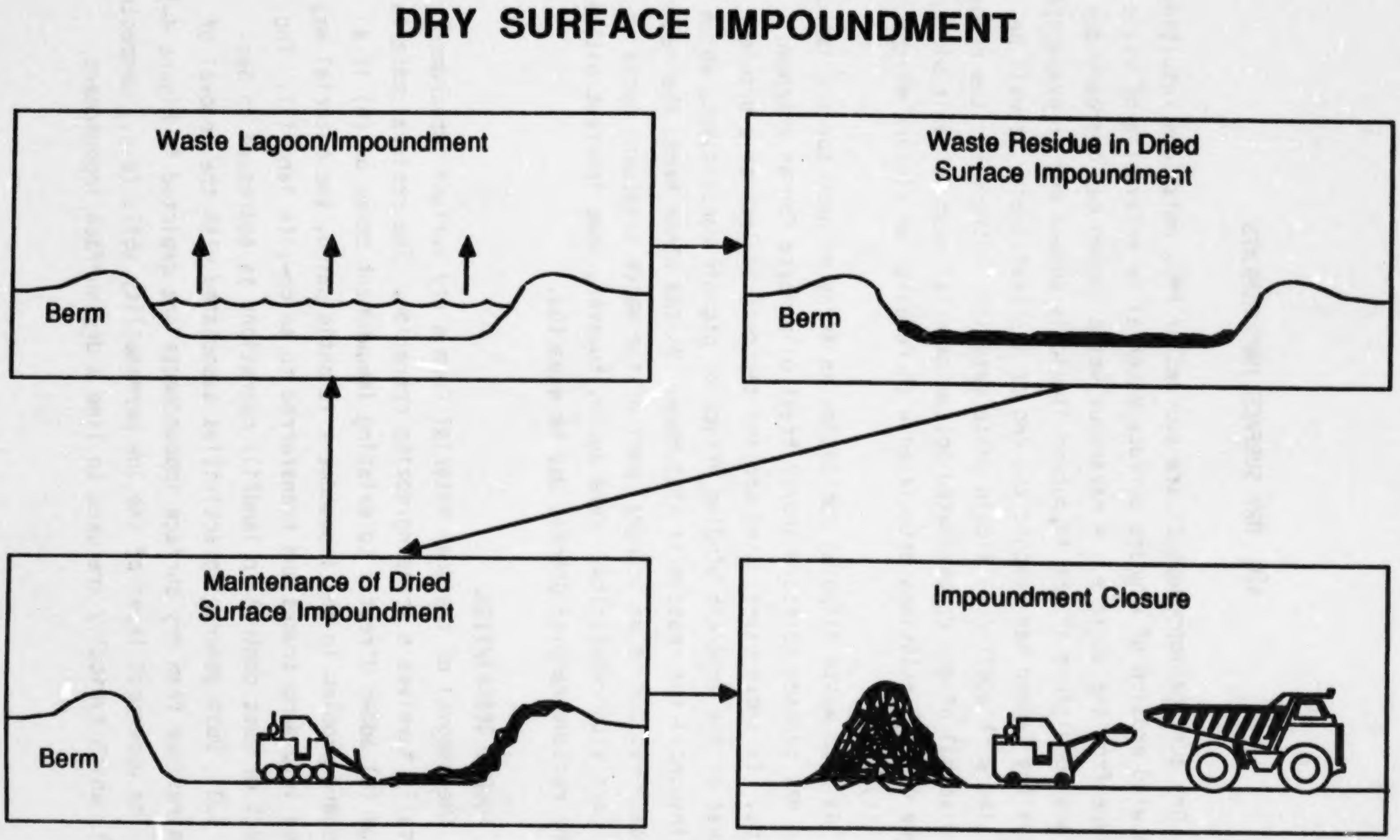
DRY SURFACE IMPOUNDMENT
Waste Lagoon/Impoundment
Berm
Waste Residue in Dried Surface Impoundment
Berm
Maintenance of Dried Surface Impoundment
Berm
Impoundment Closure

Figure 4-1. Surface impoundment activities.

contains the highest contaminant concentration. Therefore, particulate emissions from this layer contribute the highest percentage of contaminant emissions.

4.2 ESTIMATION OF UNCONTROLLED EMISSIONS

The two major sources of emissions from a dry surface impoundment are (a) wind erosion and (b) mechanical disturbance associated with the removal of waste residue.

4.2.1 Wind Erosion

With regard to estimating particulate emissions from wind erosion of exposed surface material, site inspection can be used to determine the potential for continuous wind erosion. The two basic requirements for wind erosion are that the surface be dry and exposed to the wind.

Nonhomogeneous surfaces impregnated with nonerodible elements (stones, clumps of vegetation, etc.) are characterized by the finite availability ("limited reservoir") of erodible material. Such surfaces have high threshold wind speeds for wind erosion, and particulate emission rates tend to decay rapidly during an erosion event. On the other hand, bare surfaces of finely divided material such as sandy soil (uncharacteristic of dry surface impoundments) are represented by an "unlimited reservoir" of erodible particles. Such surfaces have low threshold wind speeds for wind erosion, and particulate emission rates are relatively time independent at a given wind speed.

The clay soils that usually line surface impoundments have a pronounced tendency for crust formation as the surface dries. Crusted surfaces are regarded as having a "limited reservoir" of erodible particles. Crust thickness and strength should be examined during the site inspection, by testing with a pocket knife. If the crust is more than 0.6 cm thick and not easily crumbled between the fingers (modulus of rupture > 1 bar), then the soil may be considered nonerodible. If the crust thickness is less than 0.6 cm or is easily crumbled, then the surface should be treated as having a limited reservoir of erodible particles. If a crust is found beneath a loose deposit, the amount of this loose deposit, which constitutes the limited erosion reservoir, should be carefully estimated.

In the case of surfaces characterized by a "limited reservoir" of erodible particles, even the highest mean atmospheric wind speeds are usually not sufficient to sustain wind erosion. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mi contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries.[1] The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \qquad (4\text{-}1)$$

where: u = wind speed, cm/s

u^* = friction velocity, cm/s

z = height above test surface, cm

z_0 = roughness height, cm

0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y-intercept of the velocity profile, i.e., the height at which the wind speed is zero.

These parameters are illustrated in Figure 4-2 for a roughness height of 0.1 cm.

The roughness height, z_0, which is related to the size and spacing of surface roughness elements, is needed to convert the friction velocity to the equivalent wind speed at the typical weather station sensor height of 7 to 10 m above the surface. Figure 4-3 depicts the roughness height scale for various conditions of ground cover.[2] The conversion to the 7-m value is discussed below.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m²-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \qquad (4\text{-}2)$$

where: k = particle size multiplier

N = number of disturbances per year

P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the i-th period between disturbances, g/m²

The particle size multiplier (k) for Equation 4-2 varies with aerodynamic particle size, as follows:

Aerodynamic Particle Size Multipliers for Equation 4-2

<30 µm	<15 µm	<10 µm	<2.5 µm
1.0	0.6	0.5	0.2

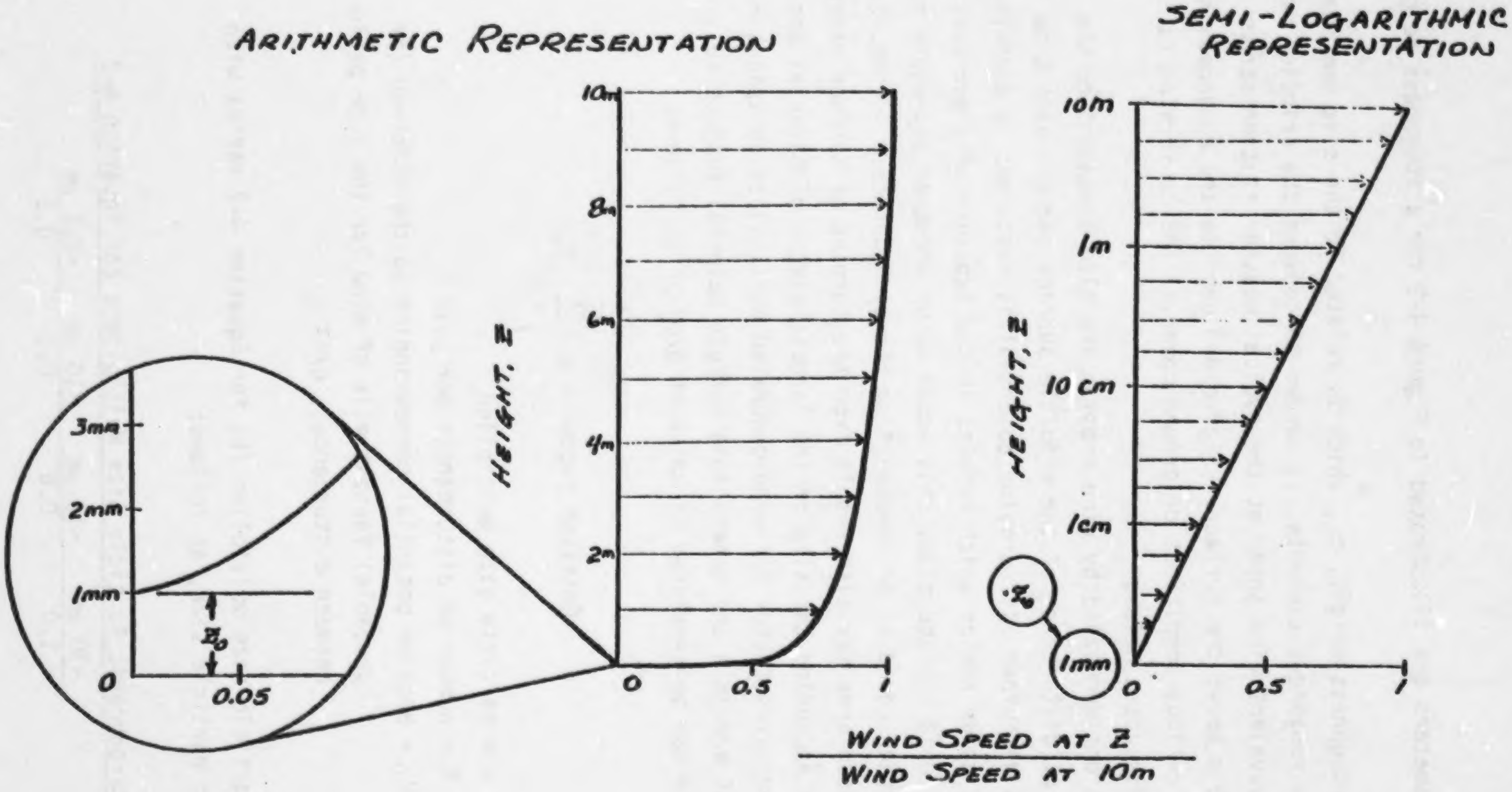

Figure 4-2. Illustration of logarithmic velocity profile.

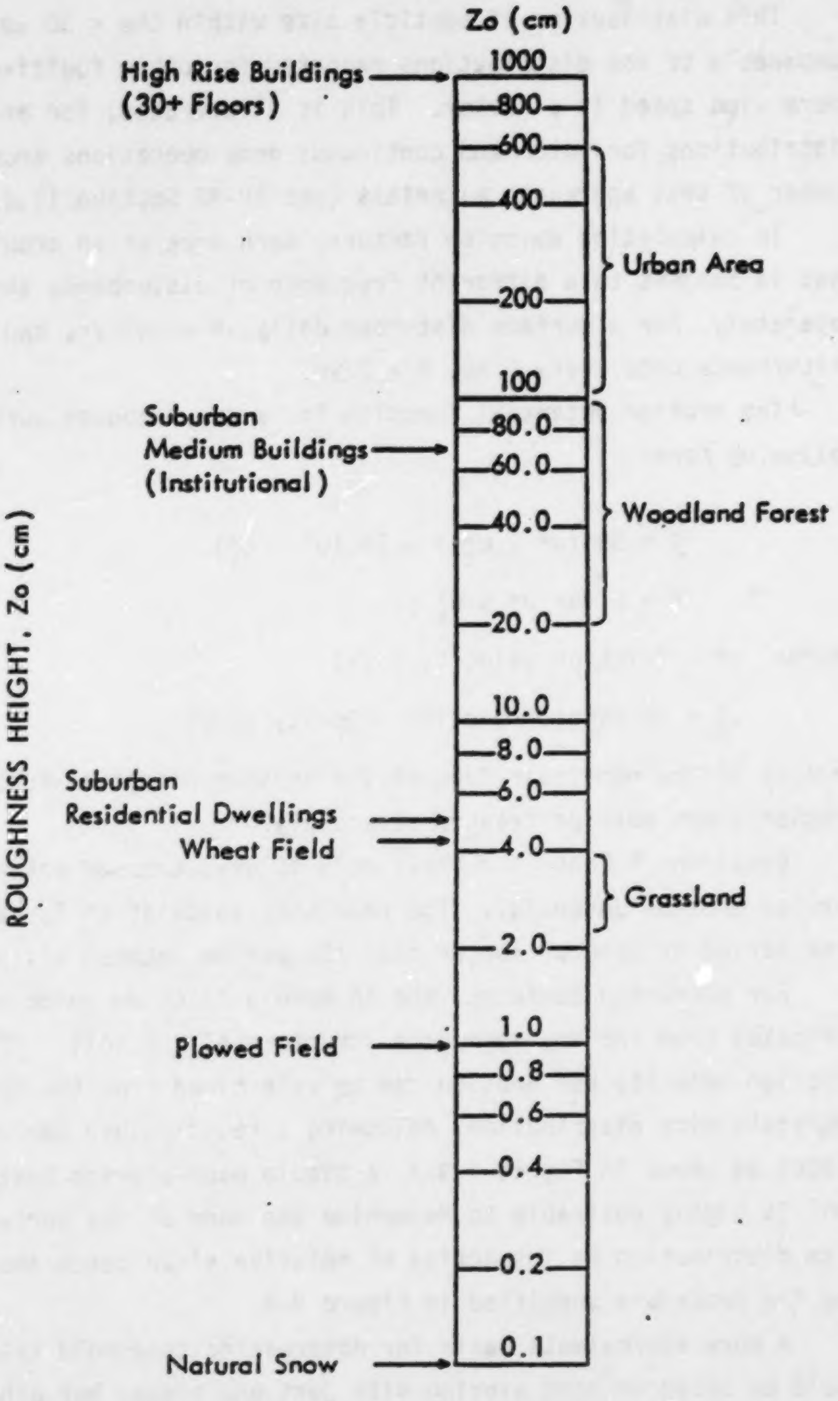

Figure 4-3. Roughness heights for various surfaces.

This distribution of particle size within the < 30 μm fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see AP-42 Section 11.2.3).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, $N = 365/\text{yr}$, and for a surface disturbance once every 6 mo, $N = 2/\text{yr}$.

The erosion potential function for a dry, exposed surface has the following form:

$$P = 58\,(u^* - u_t^*)^2 + 25\,(u^* - u_t^*) \tag{4-3}$$

$$P = 0 \text{ for } u^* \le u_t^*$$

where: u^* = friction velocity (m/s)

u_t^* = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 4-2 and 4-3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, following a relationship derived by Gillette (1980) as shown in Figure 4-4.[3] A simple hand-sieving test of surface soil is highly desirable to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure specified in Figure 4-5.

A more approximate basis for determining threshold friction velocity would be based on hand sieving with just one sieve, but otherwise follows the procedure specified in Figure 4-5. Based on the relationship

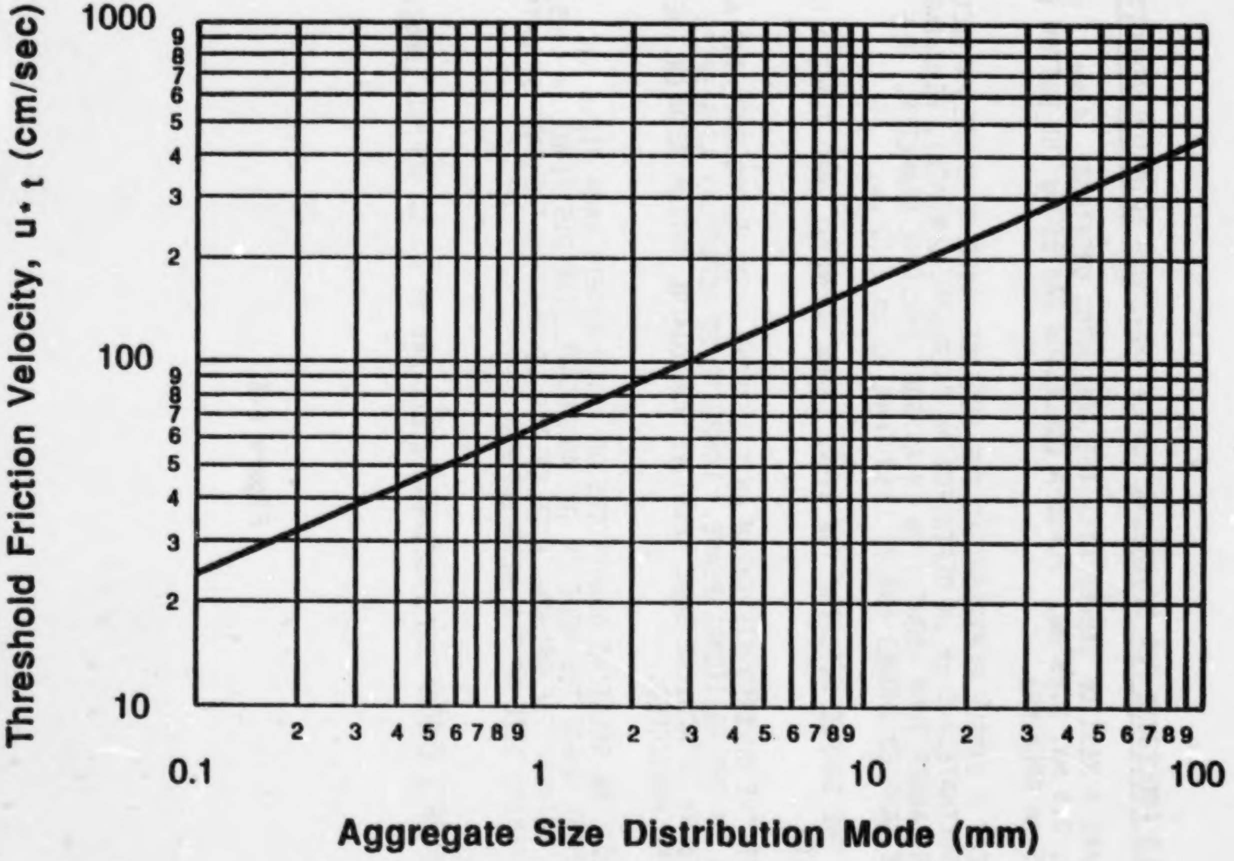

Figure 4-4. Relationship of threshold friction velocity to size distribution mode.

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY*

1. PREPARE A NEST OF SIEVES WITH THE FOLLOWING OPENINGS: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. PLACE A COLLECTOR PAN BELOW THE BOTTOM SIEVE (0.25-mm OPENING).

2. COLLECT A SAMPLE REPRESENTING THE SURFACE LAYER OF LOOSE PARTICLES (APPROXIMATELY 1 cm IN DEPTH FOR AN UNCRUSTED SURFACE), REMOVING ANY ROCKS LARGER THAN ABOUT 1 cm IN AVERAGE PHYSICAL DIAMETER. THE AREA TO BE SAMPLED SHOULD NOT BE LESS THAN 30 cm x 30 cm.

3. POUR THE SAMPLE INTO THE TOP SIEVE (4-mm OPENING), AND PLACE A LID ON THE TOP.

4. ROTATE THE COVERED SIEVE/PAN UNIT BY HAND USING BROAD SWEEPING ARM MOTIONS IN THE HORIZONAL PLANE. COMPLETE 20 ROTATIONS AT A SPEED JUST NECESSARY TO ACHIEVE SOME RELATIVE HORIZONTAL MOTION BETWEEN THE SIEVE AND THE PARTICLES.

5. INSPECT THE RELATIVE QUANTITIES OF CATCH WITHIN EACH SIEVE AND DETERMINE WHERE THE MODE IN THE AGGREGATE SIZE DISTRIBUTION LIES, I.E., BETWEEN THE OPENING SIZE OF THE SIEVE WITH THE LARGEST CATCH AND THE OPENING SIZE OF THE NEXT LARGEST SIEVE.

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*ADAPTED FROM A LABORATORY PROCEDURE PUBLISHED BY W. S. CHEPIL (1952).[4]

Figure 4-5

developed by Bisal and Ferguson (1970), if more than 60 percent of the soil passes a 1-mm sieve, the "unlimited reservoir" model will apply; if not, the "limited reservoir" model will apply.[5] This relationship has been verified by Gillette (1980) on desert soils.[3]

If the soil contains nonerodible elements which are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of these elements must be taken into account by increasing the threshold friction velocity. Marshall (1971) has employed wind tunnel studies to quantify the increase in the threshold velocity for differing kinds of nonerodible elements.[6] His results are depicted in terms of a graph of the rate of corrected to uncorrected friction velocity versus L_c (Figure 4-6), where L_c is the ratio of the silhouette area of the roughness elements to the total area of the bare loose soil. The silhouette area of a nonerodible element is the projected frontal area normal to the wind direction.

A value for L_c is obtained by marking off a 1-m x 1-m surface area and determining the fraction of area, as viewed from directly overhead, that is occupied by nonerodible elements. Then the overhead area should be corrected to the equivalent frontal area; for example, if a spherical nonerodible element is half embedded in the surface, the frontal area is one-half of the overhead area. Although it is difficult to estimate L_c for values below 0.05, the correction-to-friction velocity becomes less sensitive to the estimated value of L_c.

The difficulty in estimating L_c also increases for small nonerodible elements. However, because small nonerodible elements are more likely to be evenly distributed over the surface, it is usually acceptable to examine a smaller surface area, e.g., 30 cm x 30 cm.

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Tables 4-1 and 4-2 and Figure 4-7.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.[1] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate.

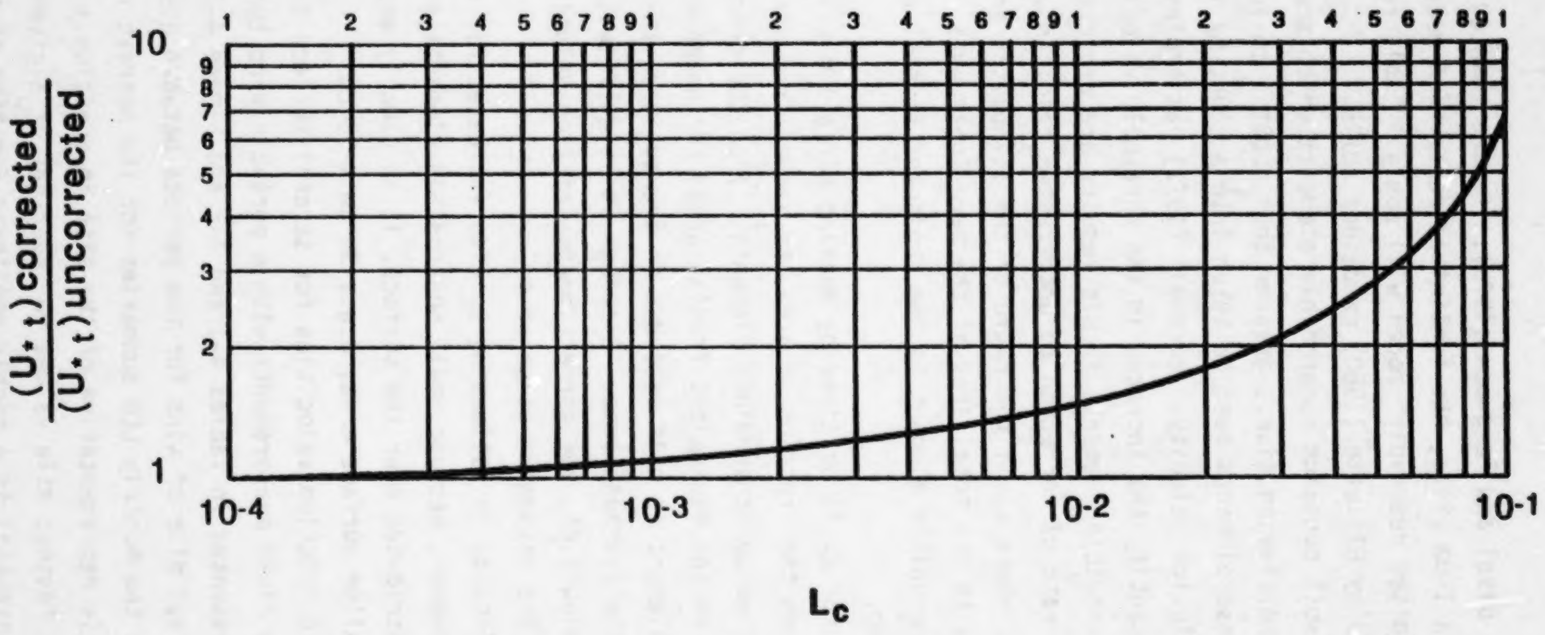

Figure 4-6. Increase in threshold friction velocity with L_c.

TABLE 4-1. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)		Ref.
			z_0 = Actual	z_0 = 0.5 cm	
Overburden[a]	1.02	0.3	21	19	8
Scoria (roadbed material)[a]	1.33	0.3	27	25	8
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	8
Uncrusted coal pile[a]	1.12	0.3	23	21	8
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	8
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	9

[a] Western surface coal mine (Reference 7).

[b] Lightly crusted.

[c] Eastern power plant (Reference 8).

TABLE 4-2. THRESHOLD FRICTION VELOCITIES--ARIZONA SITES

Location	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)
Mesa - Agricultural site	0.57	0.0331	16
Glendale - Construction site	0.53	0.0301	15
Maricopa - Agricultural site	0.58	0.1255	14
Yuma - Disturbed desert	0.32	0.0731	8
Yuma - Agricultural site	0.58	0.0224	17
Algodones - Dune flats	0.62	0.0166	18
Yuma - Scrub desert	0.39	0.0163	11
Santa Cruz River, Tucson	0.18	0.0204	5
Tucson - Construction site	0.25	0.0181	7
Ajo - Mine tailings	0.23	0.0176	7
Hayden - Mine tailings	0.17	0.0141	5
Salt River, Mesa	0.22	0.0100	7
Casa Grande - Abandoned agricultural land	0.25	0.0067	8

Source: Reference 9.

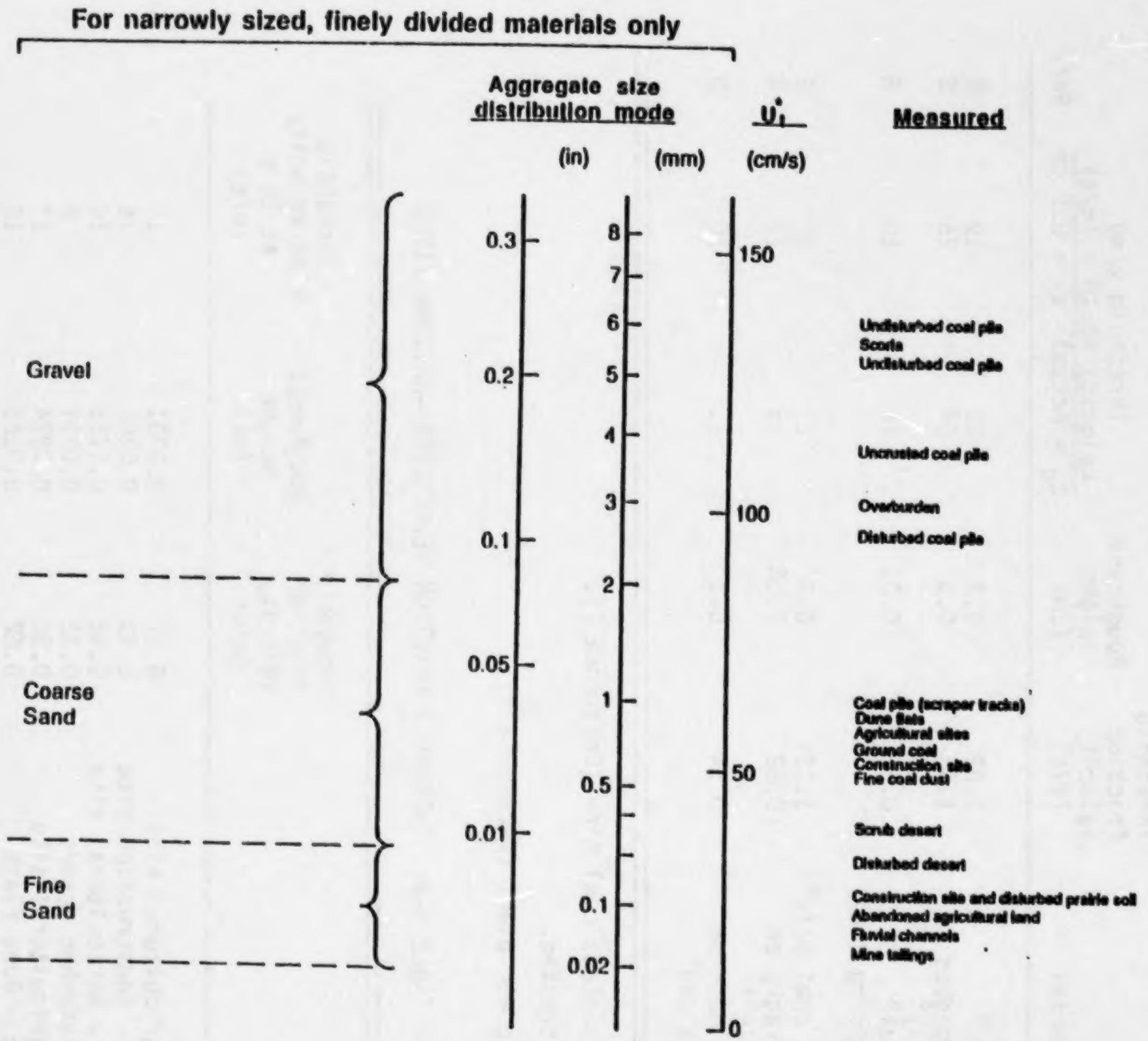

Figure 4-7. Scale of threshold friction velocities.

The anemometer heights of reporting weather stations are found in Reference 10, and wind speeds should be corrected to a 10 m reference height using Eq. 4-1.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\, u_{10}^+ \qquad (4\text{-}4)$$

where: u^* = friction velocity (m/s)
u_{10}^+ = fastest mile of wind from reference anemometer (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4-4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Tables 4-1 and 4-2 or use Figure 4-4 to determine the mode of the aggregate size distribution).
2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them from the anemometer height (z) to 10 m (u_{10}^+) using a variation of Equation 4-1, as follows:

$$u_{10}^+ = u^+ \frac{\ln(10/0.005)}{\ln(z/0.005)} \qquad (4\text{-}5)$$

   where a typical roughness height of 0.5 cm (0.005 m) has been used.
4. Convert fastest mile values (u_{10}^+) to equivalent friction velocities (u^*), taking into account uniform wind exposure of nonelevated surfaces, using Equation 4-4.
5. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_i) for each period

between disturbances using Equation 4-3 and the emission factor using Equation 4-2.

6. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-h emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 min, which corresponds roughly to the half-life for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process which offset this apparent conservatism:

1. The fastest mile event contains peak winds which substantially exceed the mean value for the event.
2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed which contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

4.2.2 Removal of Surface Material

At present, the only emission factor available in AP-42 for construction-related activities is 1.2 tons/acre/month (related to particles < 30 μm Stokes' diameter). However, PM_{10} emission factors have been developed for construction site preparation using test data from a study conducted in Minnesota for topsoil removal, earthmoving (cut-and-fill), and truck haulage operations. For these operations, the PM_{10} emission factors based on the level of vehicle activity (i.e., vehicle kilometers traveled or VKT) occurring on-site are:[11]

- Topsoil removal: 5.7 kg/VKT for pan scrapers
- Earthmoving: 1.2 kg/VKT for pan scrapers
- Truck haulage: (uncompacted surfaces) 2.8 kg/VKT for haul trucks

The following equation is recommended for estimating emissions from transfer operations (batch or continuous drop) involving aggregate materials:

$$e = k(0.0016)\,\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ (\text{kg/Mg})$$

(4-6)

$$e = k(0.0032)\,\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ (\text{lb/ton})$$

where: e = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed, m/s (mph)
M = material moisture content, %

The particle size multiplier k varies with aerodynamic particle diameter as shown below:

Aerodynamic Particle Size Multiplier, k

<30 µm	<15 µm	<10 µm	<5 µm	<2.5 µm
0.74	0.48	0.35	0.20	0.11

Truck dumping or loading a truck with a front-end loader are examples of batch drop operations. Adding material to a pile by a conveyor stacker is an example of a continuous drop operation.

Procedures for estimating emissions from vehicle traffic on paved roads and compacted unpaved roads are presented separately in Section 2 of this document.

4.2.3 Level of Contamination

The data presented in Reference 12 suggest several points that may be useful in specifying the level of contamination (α) for dry surface impoundments. These include:

- The question of whether or not a given organic compound is present and if so at what levels is site-specific. This suggests that source-specific S&A would, in fact, be needed to characterize α levels for organic compounds.
- If a source-specific S&A plan is being developed (see Appendix D for generic procedures), the data in Reference 12 indicate that organic compounds with lower vapor pressures tend to be found more often than compounds with high vapor pressures (i.e., volatile compounds). As a result then, the S&A plan should be directed toward organic compounds with relatively low vapor pressures (< 10 mm Hg).
- As an alternative to source-specific S&A, a "worst-case" scenario could be developed based on knowledge of the waste streams historically placed in the surface. Applying a "safety factor" of 5 or 10 may be warranted. In other words, multiply the upper end values by 5 or 10 as a conservatively high estimate of α.

4.3 DEMONSTRATED CONTROL TECHNIQUES

The control techniques applicable to dry surface impoundments fall into distinct categories as related to materials handling operations (including removal of waste residue) and wind erosion. In both cases, the control can be achieved by (a) source extent reduction, (b) source improvement related to work practices and transfer equipment, and (c) surface treatment. These control options are summarized in Table 4-3. The efficiency of these controls ties back to the emission factor relationships presented earlier in this section.

In most cases, good work practices which confine freshly exposed material provide substantial opportunities for emission reduction without the need for investment in a control application program. This statement applies to areas around the impoundment as well as the impoundment itself. In particular, spillage of material during removal of waste residue can add a large source component associated with traffic-entrained dust. Emission inventory calculations show, in fact, that the traffic dust component may easily dominate emissions from transfer of material and wind erosion. The prevention of spillage and subsequent spreading of material by vehicle tracking is essential to cost-effective emission control. If spillage cannot be prevented because of the need for intense use of mobile equipment in the surface impoundment area, then regular cleanup should be employed as a necessary mitigative measure.

Wind erosion control of soil surfaces is accomplished by stabilizing erodible particles. The stabilization process is accomplished in three major successive stages: (a) trapping of moving soil particles, (b) consolidation and aggregation of trapped soil particles, and (c) stabilization of the surface.[13]

The trapping of eroding soil is termed "stilling" of erosion. This may be effected by roughening the surface, by placing barriers in the path of the wind, or by burying the erodible particles during tillage. Trapping is accomplished naturally by soil crusting resulting from rain. It should be stressed that the stilling of erosion is only temporary; to effect a permanent control, surface stabilization must be established and maintained.

In bare soils containing a mixture of erodible and nonerodible fractions, the quantity of soil eroded by the wind is limited by the height and number of nonerodible particles that become exposed on the surface. The removal of erodible particles continues until the height of the nonerodible particles that serve as barriers to the wind is increased to a degree that affords complete shelter to the erodible fractions. If the nonerodible barriers are small, such as fine gravel, a relatively large number of pieces are needed for protection of soil from wind erosion. The gravel in such a case would protect the erodible portion more by covering than by sheltering from the wind. Thus all nonerodible materials on the ground that control erosion have an element of cover in addition to the barrier principle which protects the soil.

TABLE 4-3. CONTROL TECHNIQUES FOR DRY SURFACE IMPOUNDMENTS

Removal of waste residue	
Source extent reduction	Mass transfer reduction
Source improvement	Drop height reduction Wind sheltering Moisture retention
Surface treatment	Wet suppression
Wind erosion	
Source extent reduction	Disturbed area reduction Disturbance frequency reduction Spillage cleanup
Source improvement	Spillage reduction Wind exposure reduction
Surface treatment	Wet suppression Chemical stabilization

The above principles extend to almost all elements used in wind erosion control. All of these control methods are designed to (a) take up some or all of the wind force so that only the residual force, if any, is taken up by the erodible soil fractions; and (b) trap the eroded soil, if any, on the lee side or among surface roughness elements or barriers, thereby reducing soil avalanching and intensity of erosion.

Preventative methods which change the properties or exposure of transfer streams or surface materials are discussed in the following section.

4.4 CONTROL PERFORMANCE ESTIMATION

Preventive methods for control of emissions from dry surface impoundments typically consist of physical stabilization, chemical stabilization, and wind fences/barriers.

In controlling emissions from the removal of dry waste residue, two operations must be considered: the movement of vehicles over the surface; and the excavation of the residue itself. Watering and wet suppression, respectively, are possible control measures for these two activities.

However, use of water-based dust suppression systems may result in unacceptable increases in contaminated leachate production. Thus, before instituting a watering program, the facility must demonstrate that addition of water to the waste residue does not produce undesirable impacts on ground and surface water quality.

In the sections that follow, these methods are discussed with respect to their characteristics and effectiveness in controlling fugitive particulate emissions from dry surface impoundments.

4.4.1 Physical Stabilization

Physical stabilization by covering the exposed surface with less erodible aggregate material and/or vegetative stabilization are also practical control methods with respect to surface impoundment closure operations.

The effectiveness of control is evaluated in terms of the increase in the threshold friction velocity provided by the armoring aggregate or vegetative cover. Data on threshold friction velocities for various aggregate materials are presented in Section 4.2.

4.4.2 Chemical Stabilization

A portable wind tunnel has been used to measure the control of coal surface wind erosion emissions by a 17% solution of Coherex® in water applied at an intensity of 3.4 L/m^2 (0.74 gal/yd^2), and a 2.8% solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 6.8 L/m^2 (1.5 gal/yd^2).[14] The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 d before the test, under a wind of 15.0 m/s (33.8 mph) at 15.2 cm (6 in) above the ground, was 89.6% for TP and approximately 62% for IP and FP. The control efficiency of the latex binder on a low volatility coking coal is shown in Figure 4-8.

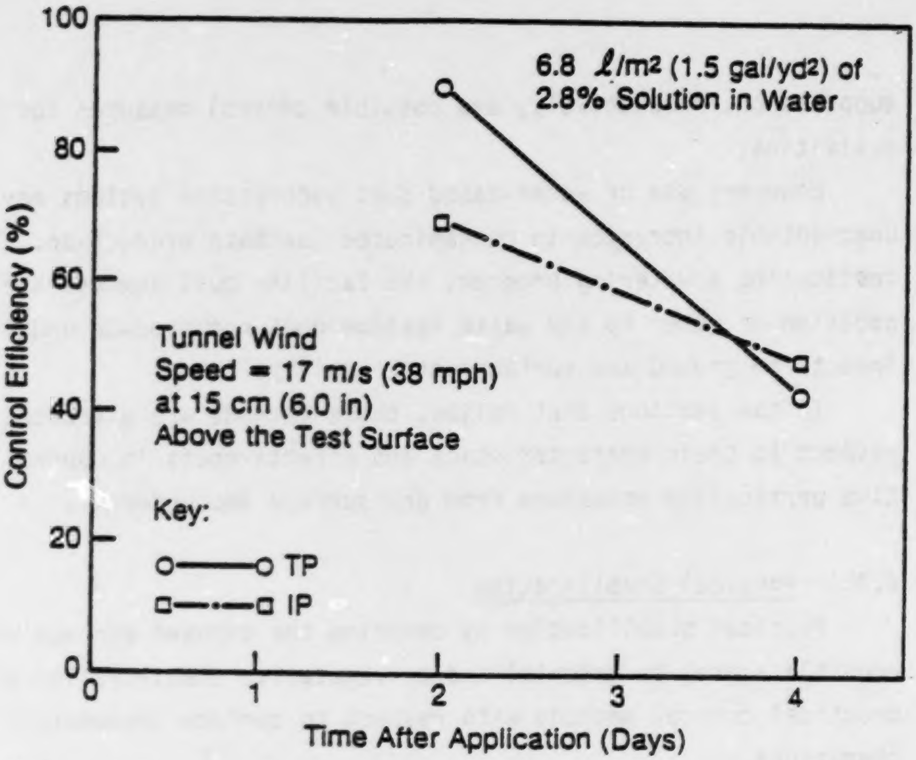

Figure 4-8. Decay in control efficiency of latex binder applied to coal storage piles.[14]

Cost elements for chemical stabilization are presented in Table 4-4. The cost of a system for application of surface crusting chemicals to storage piles is \$18,400 for the initial capital cost and \$0.006 to \$0.011/ft^2 for annual operating expenses based on April 1985 dollars.[15] Tables 4-5 and 4-6 provide recordkeeping forms for application of chemical dust suppressants.

4.4.3 Wind Fences/Barriers

Wind fences/barriers are an effective means by which to control fugitive particulate emissions from open dust sources. The principle of the wind fence/barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier. They can be used to provide a sheltered area for materials handling operations to reduce entrainment during load-in/load-out, etc.

TABLE 4-4. CAPITAL AND O&M ITEMS FOR CHEMICAL STABILIZATION OF OPEN AREA SOURCES

Capital equipment

- Storage equipment
  - Tanks
  - Railcars
  - Pumps
  - Piping

- Application equipment
  - Trucks
  - Spray system
  - Piping (including winterizing)

O&M expenditures

- Utility or fuel costs
  - Water
  - Electricity
  - Gasoline or diesel fuel

- Supplies
  - Chemicals
  - Repair parts

- Labor
  - Application time
  - Road conditioning
  - System maintenance

TABLE 4-5. TYPICAL FORM FOR RECORDING CHEMICAL DUST SUPPRESSANT CONTROL PARAMETERS

Date	Time	Type of chemical	Dilution ratio	Application intensity, gal/yd^2	Area(s) treated	Equipment used	Operator initials	Comments

TABLE 4-6. TYPICAL FORM FOR RECORDING DELIVERY OF CHEMICAL DUST SUPPRESSANTS

Date	Time	Chemical delivered	Quantity delivered	Delivery agent	Facility destination[a]	Comments

[a] Denote whether suppressant will be applied immediately upon receipt or placed in storage.

Wind fences/barriers can either be man-made structures or vegetative in nature. Wind screens or fences reduce the mechanical turbulence generated by ambient winds in an area the length of which is many times the physical height of the fence. Fences and screens can be portable and thus capable of being moved around the site, as needed.

A number of studies have attempted to determine the effectiveness of wind fences/barriers for the control of windblown dust under field conditions. Several of these studies have shown both a significant decrease in wind velocity as well as an increase in sand dune growth on the lee side of the fence.[16-18] The degree of emissions reduction varied substantially from study to study depending on test conditions.[17,19]

Control Efficiency. The control efficiency of wind fences is dependent on the physical dimensions of the fence relative to the source being controlled. In general, a porosity (i.e., percent open area) of 50 percent seems to be optimum for most applications. According to a recent field study of soil storage piles, a screen length of five times the pile diameter, a screen-to-pile distance of twice the pile height, and a screen height equal to the pile height was found best.[20] Also, a 1988 wind tunnel study of windbreak effectiveness for coal storage piles showed 49% to 97% control efficiencies for a 50% porosity windbreak with height equal to the pile height and length equal to the pile base.[21] The windbreak was located three pile heights upwind from the base of the pile.

Control Costs. As stated above, one of the real advantages of wind fences for the control of PM_{10} involves the low capital and operating costs. These involve the following basic elements:

- Capital equipment:
    - Fence material and supports
    - Mounting hardware
- Operating and maintenance expenditures:
    - Replacement fence material and hardware
    - Maintenance labor

The following cost estimates (in 1980 dollars) were developed for wind screens applied to aggregate storage piles:[22]

- Artificial wind guards:
  - -- Initial capital cost = $12,000 to $61,000
- Vegetative wind breaks:
  - -- Initial capital cost = $45 to $425 per tree

Due to the lack of quantitative data on costs associated with wind screens, it is recommended that local vendors be contacted to obtain more detailed data for capital and operating expenses. Also, since wind fences and screens are relatively "low tech" controls, it may be possible for the site operator to construct the necessary equipment using site personnel with less expense.

Compliance Issues. As with other options mentioned above, the main regulatory approach involved with wind fences and screens would involve recordkeeping by the site operator. Parameters to be specified in the dust control plan and routinely recorded are:

General Information to be Specified in Plan

1. Locations of all materials handling operations to be controlled with wind fences referenced on a plot plan available to the site operator and regulatory personnel
2. Physical dimensions of each source to be controlled and configuration of each fence or screen to be installed
3. Physical characteristics of material to be handled or stored for each operation to be controlled by fence(s) or screen(s)
4. Applicable prevailing meteorological data (e.g., wind speed and direction) for site on an annual basis

Specific Operational Records

1. Date of installation of wind fence or screen and initials of installer
2. Location of installation relative to source and prevailing winds
3. Type of material being handled and stored and physical dimensions of source controlled
4. Date of removal of wind fence or screen and initials of personnel involved

General Records to be Kept

1. Fence or screen maintenance record
2. Log of meteorological conditions for each day of site operation

4.4.4 Watering of Unpaved Surfaces

Watering of unpaved surfaces is one form of wet dust suppression. This technique prevents (or suppresses) the fine particulate from leaving the surface and becoming airborne through the action of mechanical disturbance or wind. The water acts to bind the small particles to the larger material thus reducing emissions potential.

Control Efficiency: The control efficiency of watering of unpaved surfaces is a direct function of the amount of water applied per unit surface area (liters per square meter), the frequency of application (time between reapplication), the volume of traffic traveling over the surface between applications, and prevailing meteorological conditions (e.g., wind speed, temperature, etc.). As stated previously, a number of studies have been conducted with regard to the efficiency of watering to control dust, but few have quantified all parameters listed above.

The only specific control efficiency data which are available for vehicle travel on uncompacted surfaces involve the use of watering to control truck haulage emissions for a road construction project in Minnesota.[23] Using the geometric means of the important source characteristics (i.e., silt content, traffic volume, and surface moisture) and the regression equation developed from the downwind concentration data, a PM_{10} control efficiency of approximately 50 percent was obtained for a water application intensity of approximately 0.2 gal/yd^2/h.

For more compacted unpaved surfaces, an empirical model for the performance of watering as a control technique has been developed. The supporting data base consists of 14 tests performed in four states during five different summer and fall months. The model is:[15]

$$C = 100 - \frac{0.8\,p\,d\,t}{i} \qquad (4\text{-}7)$$

where C = average control efficiency, in percent

p = potential average hourly daytime evaporation rate in mm/h

d = average hourly daytime traffic rate in vehicles per hour
i = application intensity in L/m^2
t = time between applications in h

The term p in the above equation is determined using Figure 4-9 and the relationship:

$$p = \begin{cases} 0.0049\ e \text{ (annual average)} & \text{(4-8a)} \\ 0.0065\ e \text{ (worst case)} & \text{(4-8b)} \end{cases}$$

where p = potential average hourly daytime evaporation rate (mm/h)
e = mean annual pan evaporation (inches) from Figure 4-9

Note that no data are available for Alaska and Hawaii in Figure 4-9. Readers responsible for those portions of the country should consult local meteorological resources (e.g., state universities, local weather stations, etc.).

An alternative approach (which is potentially suitable for a regulatory format) is shown as Figure 4-10. Figure 4-10 shows that, between the average uncontrolled moisture content and a value of twice that, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. Furthermore, this relationship is applicable to all size ranges considered:

$$c = \begin{cases} 75\ (M-1) & 1 \leq M < 2 \\ 62 + 6.7\ M & 2 \leq M \leq 5 \end{cases} \qquad (4\text{-}9)$$

where c = instantaneous control efficiency in percent
M = ratio of controlled to uncontrolled surface moisture contents

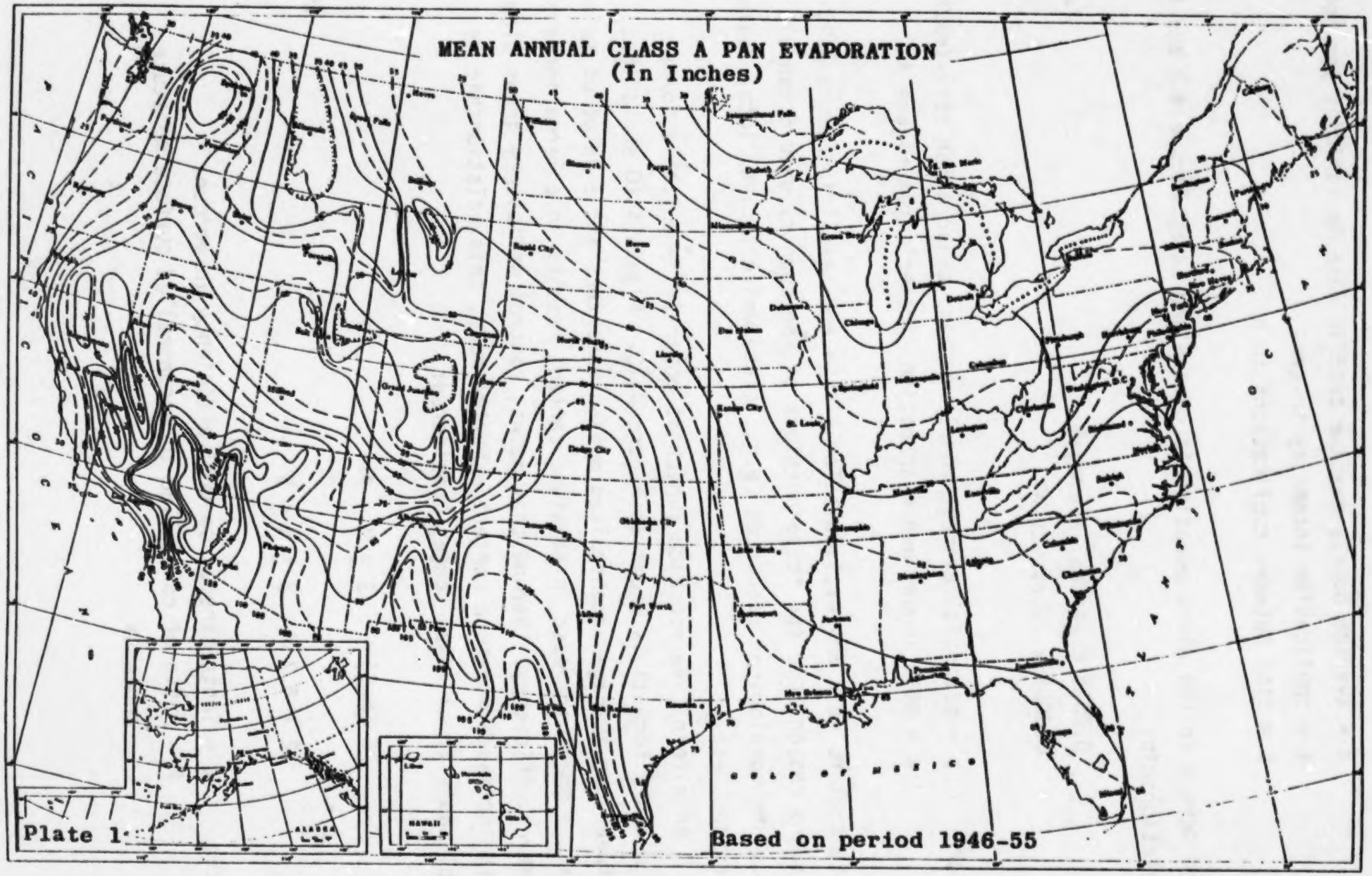
MEAN ANNUAL CLASS A PAN EVAPORATION
(In Inches)
PACIFIC OCEAN
GULF OF MEXICO
ALASKA
HAWAII
Plate 1
Based on period 1946-55

Figure 4-9. Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).

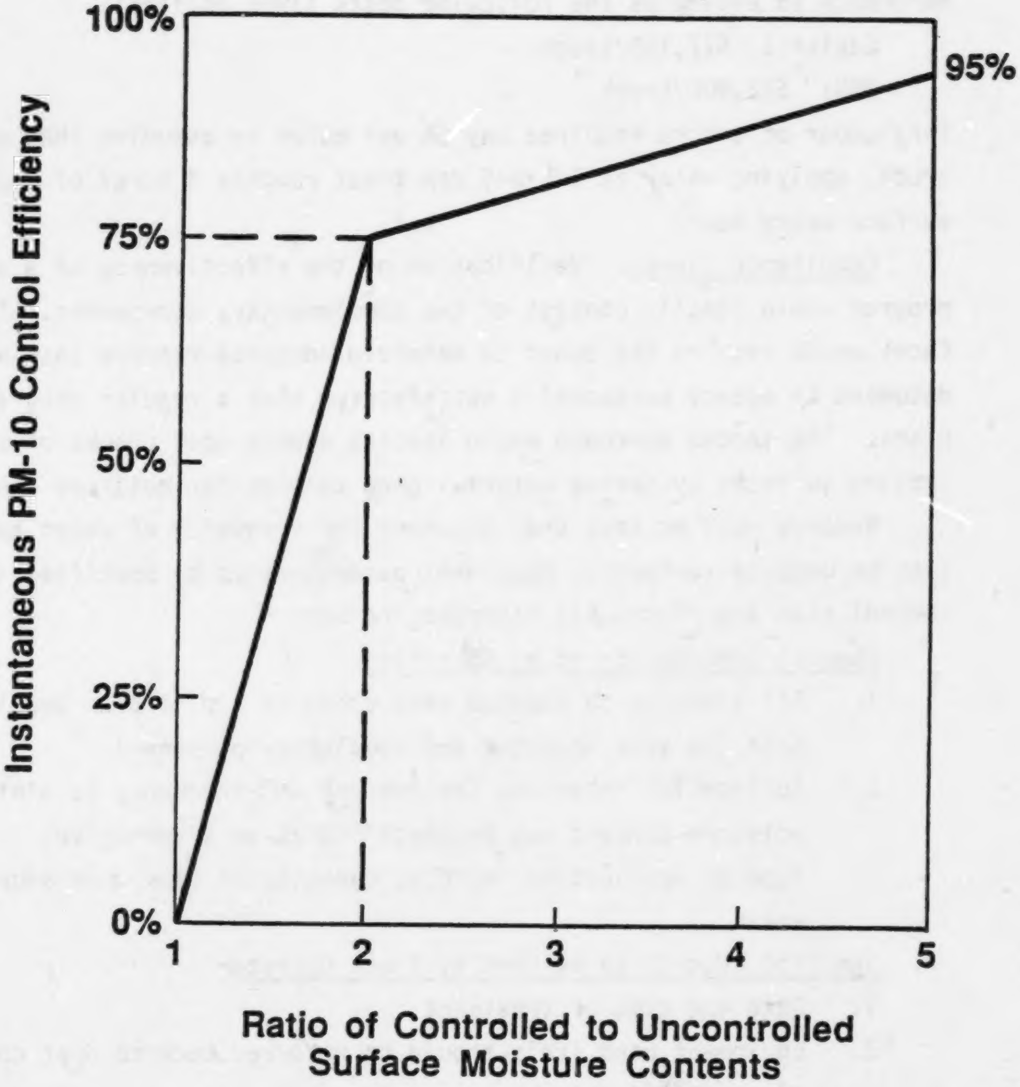

Figure 4-10. Watering control efficiency effectiveness for scraper travel on unpaved surfaces.[24]

Control Costs. Costs for watering programs include the following elements:

- Capital: Purchase of truck or other device
- O&M: Fuel, water, truck maintenance, operator labor

Reference 15 estimates the following costs (1985 dollars):

Capital: $17,100/truck

O&M: $32,900/truck

The number of trucks required may be estimated by assuming that a single truck, applying water at 1 L/m^2, can treat roughly 4 acres of unpaved surface every hour.

Compliance Issues. Verification of the effectiveness of a watering program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular program is in place. The second approach would involve agency spot checks of controlled surfaces by taking material grab samples for moisture analysis.

Records must be kept that document the frequency of water application to unpaved surfaces. Pertinent parameters to be specified in a control plan and rigorously recorded include:

General Information to be Specified.

1. All areas to be treated referenced on a plot plan available to both the site operator and regulatory personnel
2. Application intensity (gal/sq yd) and frequency (a minimum moisture content may be specified as an alternative)
3. Type of application vehicle, capacity of tank, and source of water

Specific Records to be Kept by Truck Operator

1. Date and time of treatment
2. Equipment used (this should be referred back to dust control plan specifications)
3. Operator's initials (a separate operators log may be kept and transferred later to permanent records by site operator)
4. Start and stop time, average speed, and number passes
5. Start and stop time for filling of water tank

Specific Records to be Kept by Site Operator

1. Equipment maintenance logs
2. Meteorological log of general conditions (e.g., sunny and warm vs. cloudy and cold)
3. Records of equipment breakdowns and downtime

An example permanent record form which may be used to record the above information is shown in Figure 4-11. In addition to the above, some regulatory formats require that records of surface sample moisture content also be kept.

4.4.5 Wet Suppression for Materials Handling

Control Efficiency. Wet suppression of materials handling operations is similar to that used for unpaved surfaces. However, in addition to plain water this technique can also use water plus a chemical surfactant or micronized foam to control fugitive PM_{10}.

Surfactants added to the water supply allow particles to more easily penetrate the water droplet and increase the total number of droplets, thus increasing total surface area and contact potential. Foam is generated by adding a chemical (i.e., detergent-like substance) to a relatively small quantity of water which is then vigorously mixed to produce small bubble, high energy foam in the 100 to 200-μm size range. The foam uses very little liquid volume, and when applied to the surface of the bulk material, wets the fines more effectively than untreated water.

As with watering of unpaved surfaces, the control efficiency of wet suppression for materials storage and handling is dependent on the same basic application parameters. These include: the amount of water, water plus surfactant, or foam applied per unit mass or surface area of material handled (i.e., liters per metric ton or square meter); if not continuous, the time between reapplications; the amount of surfactant added to the water (i.e., dilution ratio), if any; the method of application including the number and types of spray nozzles used; and applicable meteorological conditions occurring onsite.

Wet suppression can be applied to material handling operations by a variety of methods depending on the material and how it is being handled. If aggregates are batch transferred using loaders or by truck dumping, water (with or without chemicals) could be applied with a water

WATER APPLICATION LOG

Date	Time	Application Intensity (gal/yd^2)	Area(s) Treated	Climatic Parameters		Equipment Used	Operator Initials	Comments
				Amb. Temp. (°F)	Date/Amt. of Last Rainfall			

Figure 4-11. Typical form for recording watering program control parameters. (Sources: Unpaved surfaces, exposed areas, storage piles)

cannon or spray bar to the material prior to or during load-in or load-out. Foam may be a good alternative in such instances when the material is handled repeatably over the period of a day. Foam can be applied once in the handling process (e.g., as it is initially loaded into trucks) and the binding action of the bubbles will carry through subsequent handling operations.

Control of transfer operations can also be augmented using portable wind fences to provide a wind break to reduce dust generation and improve application of water to the load during transfer to haul trucks. Wind fences are discussed later in this discussion.

Available control efficiency data for wet dust suppression for materials handling and storage are limited.[15] For suppression using plain water, the most applicable efficiency information available is for feeder to belt transfer of coal in mining operations. Control efficiencies of 56 to 81 percent are reported for respirable particulate (particles < ~ 3.5 µmA) at application intensities of 6.7 to 7.1 L/Mg (1.6 to 1.7 gal/ton), respectively. Assuming that respirable particulate is essentially equivalent to PM_{10}, the above control efficiencies may be representative of similar controls for waste material handling. (The above application intensities were estimated assuming 5 min to discharge 7 Mg of coal and 1.4 L/min/spray nozzle.)

In the case of foam suppression, the most appropriate data available are for the transfer of sand from a grizzly. Using the respirable particulate control efficiencies at various foam application intensities (and assuming respirable particulate is equivalent to PM_{10}), the following equation was developed by simple linear regression of the data compiled by Cowherd and Kinsey:[15]

$$C = 8.51 + 7.96\ (A) \qquad (4\text{-}10)$$

where: $C = PM_{10}$ control efficiency in percent
A = application intensity in ft^3 foam/ton of material

A coefficient of determination (r^2) of 99.97 percent was obtained for the above equation based on the three data sets used in its derivation.

An alternate approach (which is potentially suitable for regulatory formats) involves the use of Eq. 4-6. By determining the moisture content of the material before and after wet suppression, the control efficiency can be determined by:

$$CE = 100(e_u - e_c)/e_u \tag{4-11}$$

where CE = PM_{10} control efficiency in percent
e_u = "uncontrolled" PM_{10} emission factor from Eq. 4-6
e_c = "controlled" PM_{10} emission factor from Eq. 4-6

The above calculations would necessitate the determination of the moisture content of the material. This could be accomplished by taking grab samples of the material before and after application of the wet suppression technique being employed and analyzing for moisture content.

Control Costs. Costs associated with wet suppression systems are presented in Table 4-7. Reference 15 estimates the following costs (in 1985 dollars):

- Regular watering of storage piles:
  - Initial capital cost = $18,400 per system
- Watering of exposed areas:
  - Initial capital cost = $1,053 per acre
  - Annual operating cost = $25 to $67 per acre

The costs associated with a wet suppression system using chemical surfactants for the unloading of limestone from trucks at aggregate processing plants (in 1980 dollars) have been estimated at: capital = $72,000; annual = $26,000. These costs are based on a stationary system and may not be indicative of those used at construction and demolition sites.[22]

Compliance Issues. As with watering of unpaved surfaces, verification of the effectiveness of a wet suppression control program would consist of two complementary approaches. The first would be record keeping to document that the program is being implemented and the other would be spot-checks and grab sampling. Both were discussed previously above.

TABLE 4-7. WET SUPPRESSION SYSTEM CAPITAL AND O&M COST ELEMENTS

Capital equipment

- Water spray system
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units
- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity
- Supplies
  - Surfactant
  - Screens
- Labor
  - Maintenance
  - Operation

Records must be kept that document the control plan and its implementation. Pertinent parameters to be specified in a plan and to be regularly recorded include:

General Information to be Specified in Plan

1. Locations of all materials handling operations referenced on plot plan of the site available to the site operator and regulatory personnel
2. The method and application intensity of water, etc, to be applied to the various materials and frequency of application, if not continuous
3. Dilution ratio for chemicals added to water supply, if any
4. Complete specifications of equipment used to handle the various materials and for wet suppression
5. Source of water and chemical(s), if used

Specific Operational Records

1. Date of operation and operator's initials
2. Start and stop time of wet suppression equipment
3. Location of wet suppression equipment
4. Type of material being handled and number of loads (or other measure of throughput) loaded/unloaded between start and stop time (if material is being pushed, estimate the volume or weight)
5. Start and stop times for tank filling

General Records to be Kept

1. Equipment maintenance records
2. Meteorological log of general conditions
3. Records of equipment malfunctions and downtime

In addition to the above, some of the regulatory formats suggested in Section 5.4 below require that records of material samples be kept.

4.5 PROCEDURES FOR COMPLIANCE DETERMINATION

Potential regulatory formats for control of emissions from dry surface impoundments are listed in Table 4-8. These focus on appropriate measures for compliance determination.

TABLE 4-8. COMPLIANCE DETERMINATION FOR DRY SURFACE IMPOUNDMENTS

Source	Emission surrogate	Control measure	Field audit parameter
Wind erosion	Threshold friction velocity; % VE at property line or at source; PM_{10}/TSP concentration at property line	Chemical stabilization	Surface crust and texture
		Wind sheltering	Surface wind speed
		Wet suppression	Surface moisture content
Removal of waste residue	% VE at property line or at source; PM_{10}/TSP concentration at property	Wind sheltering	Surface wind speed
		Wet suppression	Waste moisture content

4.6 EXAMPLE CALCULATION

Source Description

- Dry surface impoundment of dimensions 100 m x 100 m
- Waste residue density of 1.3 g/cc with a 2-cm dry surface layer having a moisture content of 0.5% and with subsurface material at a higher moisture level (exceeding 1.0%)
- Use of pan scraper to remove waste residue for transfer to landfill
- Scraper operation on the surface impoundment for 4-h at an average speed of 3 km/h yielding a source extent of 12 VKT. (This entails an average of three passes over each subarea of the impoundment surface)
- Site specific S&A (see Appendix D) indicates that phenanthrene is the single organic compound found in the highest concentration--60 μg/g

Calculation of Uncontrolled Emissions. The uncontrolled PM_{10} emissions from the waste residue removal operation may be estimated using the emission factor for top soil removal by pan scrapers, as presented in Section 4.2.2. The total uncontrolled PM_{10} emissions are given by

$$e_u = 5.7 \text{ kg/VKT (12 VKT)} \tag{4-12}$$

$$= 68.4 \text{ kg}$$

The estimated uncontrolled emissions of a particular contaminant would be obtained by multiplication of the above figure by the contaminant concentration (expressed as a mass fraction) in the waste residue:

$$68.4 \text{ kg} \times \frac{60 \text{ µg}}{\text{g}} \times \frac{1{,}000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ g}}{10^6 \text{ µg}}$$

$$= 4.1 \text{ g phenanthrene}$$

Target Control Efficiency: 75%

Method of Control. Apply water to the surface material during the residue removal operation. A water truck with a pressurized spray for uniform water application is required.

Demonstration of Control Program Adequacy. According to the data presented in Figure 4-10, which were based on tests of scraper travel on an unpaved surface, the target control efficiency of 75% can be achieved by doubling the moisture level of 0.5% in the dry surface layer of 2 cm thickness. This means adding 0.5% moisture to material having an approximate density of 1.3 g/cm³. A total of 0.013 g of water per square centimeter of surface needs to be added:

$$0.005 \times 1.3 \text{ g/cm}^3 \times 2 \text{ cm} = 0.013 \text{ g/cm}^2$$

Based on a water density of 1 g/cm³, this application intensity may be reexpressed as follows:

$$\frac{0.013 \text{ g}}{\text{cm}^2} \times \frac{\text{cm}^3}{1 \text{ g}} \times \frac{10{,}000 \text{ cm}^2}{1 \text{ m}^2} \times \frac{1 \text{ L}}{1{,}000 \text{ cm}^3} \tag{4-13}$$

$$= 0.13 \frac{\text{L}}{\text{m}^2}$$

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5.0 LANDFILLS

5.1 SOURCE DESCRIPTION

The placement of hazardous bulk and/or containerized solid wastes into permitted landfill units may involve a number of activities with the potential to generate PM_{10} emissions that may be contaminated by toxic constituents. The "mix" of potential dust emitting activities and, consequently, the level of particulate emissions can be expected to vary significantly from facility to facility. This variation likely depends upon a number of site attributes including:

- Whether the site is an off-site facility handling a variety of waste streams or an on-site facility confined to relatively few specific waste streams.
- The physical and chemical characteristics of the waste streams accepted at the facility, as well as the volumes of waste handled.
- The physical size of the site, its geographic location, and associated climate.
- The available equipment, operating practices, and perhaps the "age" of the disposal area (both in terms of years and relative to its expected permitted capacity).

In general terms, previous surveys[1] of hazardous waste (HW) treatment, storage, and disposal facilities (TSDFs) suggest that there are four unit operations common to HW landfills. These operations, as described below, are:

- Loadout of solid hazardous waste.
- Loadout of temporary, clean (i.e., presumably uncontaminated) cover material.
- Lift construction involving the placement and possibly compaction of hazardous waste, followed by spreading and compaction of clean cover.

- General vehicle traffic proximate to the active face of the landfill.

Wind erosion from open areas represents a fifth potential dust emitting mechanism associated with landfill units. However, as a general rule it is expected that the contribution of wind erosion to total landfill emissions will be negligible in comparison to the emissions produced by the above unit operations. Thus, it is recommended that landfill emissions calculations initially neglect wind erosion; if refinements are desired, wind erosion estimates can be obtained using the procedures described in Section 3.0.

The unit operations may involve a variety of vehicles/equipment. For convenience, Figure 5-1 provides line drawings of some of the common equipment types. These are referenced as A, B, C, and D in the discussion below.

Figure 5-2a and 5-2b show generalized versions of a landfill in plan and profile. As indicated, at a given point in time, a "typical" unit would consist of (1) a completed lift area with a "typical" height of 2 to 4 m; (2) the active face and associated loadout zone where waste is being placed; and (3) an area proximate to the face where the majority of vehicle movement occurs.

The first operation--loadout of solid hazardous waste--involves the placement of waste into the loadout zone (see Figures 5-2a and 5-2b) using vehicles with varying dumping capacities. Figure 5-1A is intended to represent a commercial hauler used to transport solid hazardous waste. These vehicles typically have capacities on the order of 15 m^3 (20 yd^3), and usually are equipped to hydraulically remove waste material from the cargo "box." Note also that smaller dump trucks may also be used to transport solid waste. A reasonable range of average dumping capacity at the surveyed TSDFs is on the order of ~ 1.5 to 15 m^3 (2 to 20 yd^3); a reasonable midpoint (i.e., mean or median) value for the distribution is probably 11.5 m^3 (15 yd^3). Note that it is quite possible that "typical" dumping capacity at a facility varies depending upon whether that facility is primarily an on-site or off-site TSDF. Because of the generally smaller volumes handled at on-site facilities, these may tend to have smaller capacity waste haulers than off-site facilities.

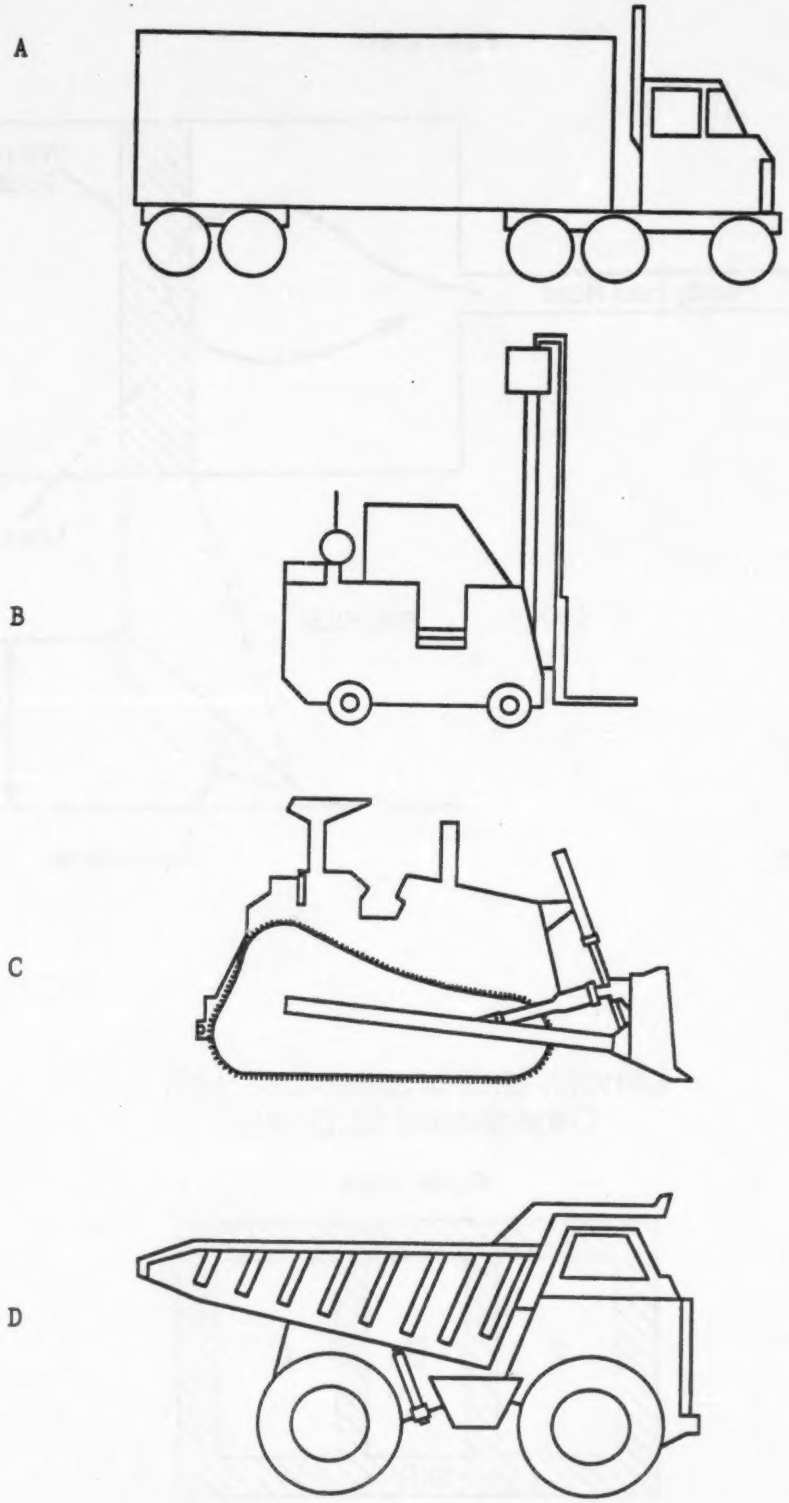
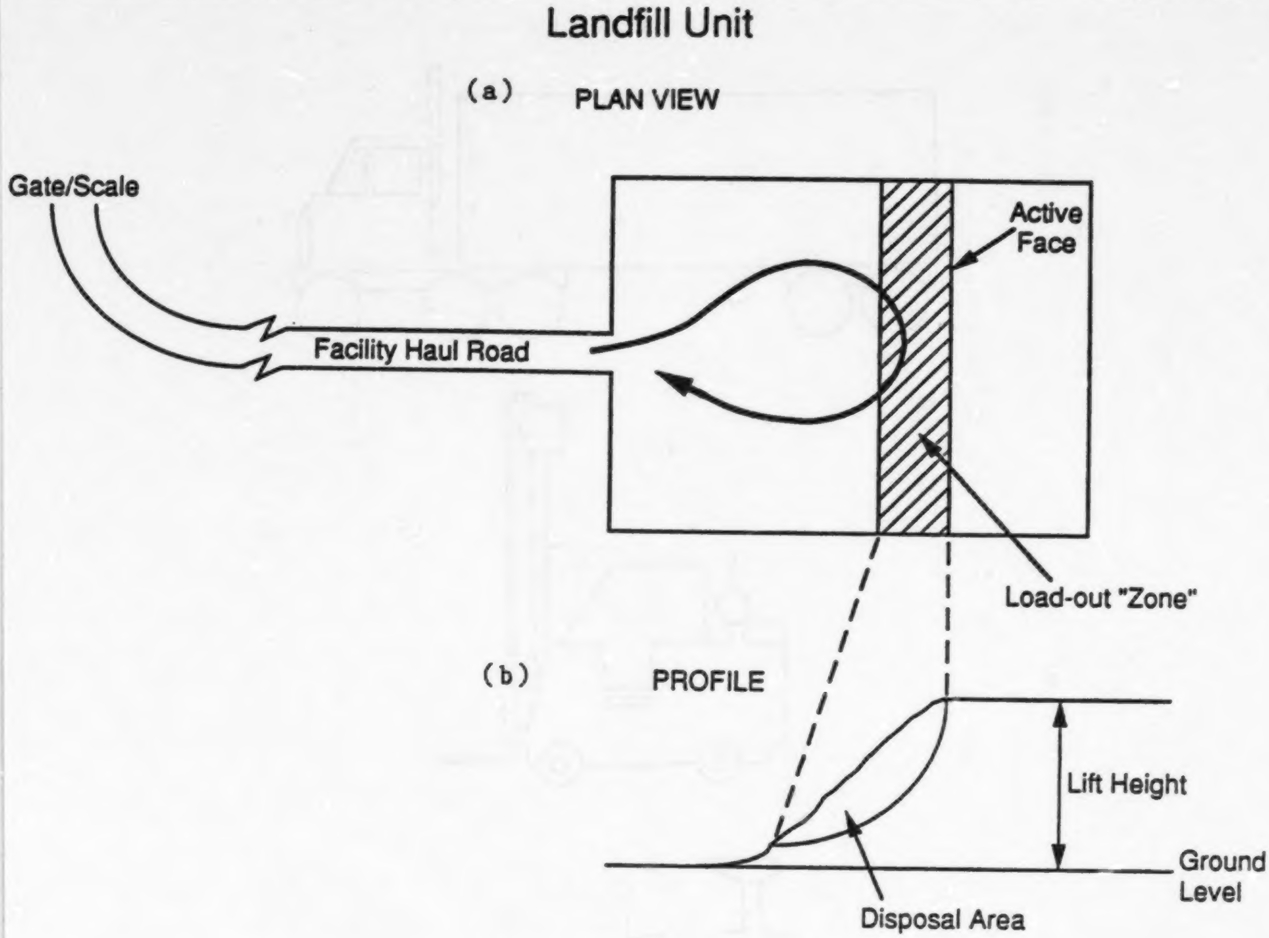


Figure 5-1. Line drawings of common equipment types at HW landfills.


Landfill Unit
(a)
PLAN VIEW
Gate/Scale
Facility Haul Road
Active Face
Load-out "Zone"
(b)
PROFILE
Lift Height
Ground Level
Disposal Area

(c) Landfill Unit-Master Cell with Designated Subcells

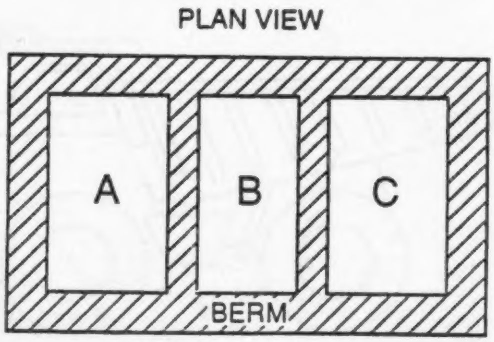

PLAN VIEW
A
B
C
BERM

Figure 5-2. (a) Hypothetical landfill unit plan view; (b) profile view; (c) hypothetical landfill with master cell/subcell configuration.

The second operation--loadout of temporary cover--is essentially identical to loadout of hazardous waste. The typical dumping capacity of the vehicles used for this operation probably is greater than for hazardous waste loadout with a reasonable midpoint value on the order of 15 to 19 m^3 (20 to 25 yd^3). If the landfill is operating properly, the completed lift area should have clean temporary cover--i.e., earth material with negligible contaminant levels. This material often is loaded out using vehicles such as Figure 5-1D--an off-road haul truck.

Methods for the third operation--lift construction--tend to be site-specific and in most cases have evolved to meet unique site parameters like waste stream volume, physical/chemical characteristics of the wastes, and site climate. The objective of lift construction is simply to move and compact the waste material in a manner that creates a structurally sound area. This lift area then forms the basis for successive lifts as the landfill capacity is gradually used. Based on observation of activities at several operating HW landfills, it appears that actual lift construction usually is accomplished by a tracked vehicle fitted with either a blade or a bucket. Other heavy equipment, such as a pan scraper or motor grader, may be used to spread temporary cover and/or waste material. In some cases a sheepsfoot compactor is used to attain the desired compaction of the material, while other facilities depend upon the routine heavy equipment movement for compaction. A typical vehicle used for lift construction is depicted in Figure 5-1C.

The fourth unit operation--general vehicle traffic--encompasses a broad spectrum of activities including hauler traffic on the lift or proximate to the landfill face, placement of containerized waste by operating landfill equipment, and light-duty vehicle traffic (i.e., pickup trucks). Containerized wastes typically are handled by a forklift or comparable equipment depicted as Figure 5-1B.

Figures 5-2a and 5-2b depict a situation in which all wastes are placed in the same area, regardless of their physical/chemical characteristics. While this may be the case at some facilities, field observations suggest that some landfill units are configured as in Figure 5-2c--a master cell with subcells. One reasonably common practice apparently is to designate placement of wastes in subcells according to the RCRA characteristic criteria for ignitability (40 CFR Part 261.21), corrosivity (40 CFR 261.22), and reactivity (40 CFR 261.23).

5.2 ESTIMATION OF UNCONTROLLED EMISSIONS

The following section presents the emission factor models used to estimate particulate emissions from landfills. It includes a summary of available data on both the physical and chemical characteristics of disturbed surfaces as well as source activity levels found at operating HW landfill units.

5.2.1 Particulate Emission Rates

Estimation of uncontrolled particulate emissions from landfills follows the general model (Eq. 1-2) presented in Section 1.2. For convenience, it is reiterated below with terms potentially applicable to landfill units:

$$R = \sum_{j=1}^{n} \alpha_j \cdot e_j \cdot A_j \qquad (5\text{-}1)$$

where: R = emission rate of contaminated airborne particulate (kg/yr) for a given landfill, consisting of n identifiable unit operations

α_j = fraction of contaminant in particulate emissions for the jth operation (µg/g); if only PM_{10} emissions are of concern, $\alpha_j = 1$

e_j = emission factor(s) (mass/source extent)

A_j = source extent(s) (source dependent units)

For landfills, n=4 with the unit operations corresponding to those outlined in Section 5.1--loadout of HW; loadout of temporary cover; lift construction; and general vehicle traffic.

Table 5-1 provides an emission factor (e_j) for each of the unit operations that may occur at a landfill. These emission factors are included in EPA's "Compilation of Air Pollutant Emission Factors" (AP-42).[2] Excepting the α_j term, there are features of each emission factor that should be clearly recognized before any estimation is performed for a given landfill unit. These features are discussed below.

For the first two unit operations (Table 5-1)--loadout of bulk waste and cover, respectively--the emission factor is based on testing of common industrial aggregates (coal, crushed limestone, sand, etc.).

For the third unit operation--lift construction and maintenance--the unit operation is assumed to generate particulate emissions at rates comparable to those determined in field source testing of a dozer operation involving overburden removal at western surface coal mines. Note further that the emission factor model developed for dozer operations actually relates to emission measurements of particulate matter less than 15 μm (PM_{15}). However, Supplement B of AP-42 recommends a PM_{15} to PM_{10} conversion factor which is reflected in Table 5-1.

For the fourth unit operation--general vehicle traffic--the activities proximate to the landfill face are assumed to be analogous to those tested in development of the unpaved road emission factor relationship (presented in Section 2.2.2.1). Although this emission factor was developed for "wheeled" vehicles on well-compacted, unpaved surfaces, it is assumed to apply to tracked vehicles as well.

Application of the emission factor expressions in Table 5-1 for a given site requires appropriate data on physical properties (e.g., vehicle speed, weight, etc.) as well as mechanical activities. Table 5-2 provides summary statistics for the various emission factor correction terms; these data were developed as part of an initial survey of land-based TSDFs. Because most of the terms exhibit significant variability from site to site, use of site-specific data to represent these parameters is highly recommended.

Table 5-3 provides mean wind speed (U) data (m/s) for selected National Western Service (NWS) stations. In general, the value of U for the reporting station located closest to the facilty in question, may be taken as data input for Eq. 5-1 to estimate emissions associated with loadout of bulk hazardous material or temporary cover.

TABLE 5-1. EMISSION FACTORS FOR HAZARDOUS WASTE LANDFILL UNIT OPERATIONS

Unit operation	Emission factor	Eq. No.	Source extent
Loadout of bulk (uncontainerized) hazardous waste	$e = 0.00056 \dfrac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$ (kg/Mg) $e = \dfrac{0.0011 \left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$ (lb/ton) where: $e = PM_{10}$ emission factor in units stated U = mean wind speed (m/s) (mph) M = moisture content (%) of the waste material	(5-1)	Mg of waste material handled
Loadout of temporary cover material	Same as above		Mg of cover material handled
Lift construction	$e = \dfrac{0.34\ (s)^{1.5}}{(M)^{1.4}}$ (kg/hr) $e = \dfrac{0.74\ (s)^{1.5}}{(M)^{1.4}}$ (lb/hr) where: $e = PM_{10}$ emission factor in units stated s = silt content (%) of the material used in lift construction (waste and cover material) M = moisture content (%) of the waste and cover material	(5-2)	Mass/time
General vehicle traffic	$e = (0.61) \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{5}\right)^{0.5} \left(\frac{365-p}{365}\right)$ (kg/VKT) $e = 2.1 \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right)$ (lb/VMT) where: $e = PM_{10}$ emission factor in units stated s = silt content (%) of the travel surface S = average vehicle speed (km/h) W = average vehicle weight (Mg) w = average vehicle wheels p = number of days with precipitation $\geq$ 0.254 mm (0.01 in)	(5-3)	Vehicle kilometers traveled (VKT)

TABLE 5-2. EMISSION FACTOR CORRECTION TERMS AND SOURCE EXTENTS FOR SAMPLED LANDFILL UNITS[a]

Unit operation/emission factor correction term/source extent	Units	No. of landfill units sampled[b]	No. of samples[c]/ observations	Correction term $\bar{x}^d$	Range
I. **Hazardous waste loadout:**					
Moisture content	% w/w	6	9	18.5	1.0-31.6
Estimated annual source extent	Mg	6	9	40,700	$35\text{-}2.9 \times 10^5$
II. **Temporary cover loadout:**[e]					
Moisture content	% w/w	4	4	13	10-16
Estimated annual source extent	Mg		NA[f]		
III. **Lift construction:**					
Silt content	% w/w	6	9	12.7	4.2-27.4
Moisture content	% w/w	6	8	19.6	1.0-31.6
Estimated annual source extent	h	5	8	1,300	180-2,200
IV. **General vehicle traffic:**					
Silt content	% w/w	6	9	12.7	4.2-27.4
Average vehicle speed	kph	6	9[g]	8[g]	NA
Average vehicle weight	Mg	6	9	20	9-36
Average No. of wheels	-	6	9	12	8-18

[a] Unless otherwise noted, data taken from Reference 1.

[b] Refers to number of individual facilities surveyed; at some facilities, more than one landfill cell was sampled.

[c] Refers to number of landfill cells sampled; for some cells, more than one sample was analyzed for moisture content.

[d] Refers to arithmetic mean.

[e] Data represent temporary cover used at municipal solid waste (MSW) landfills; data taken from References 3 and 4.

[f] Not applicable as data based on values from MSW facilities.

[g] Estimated values based on observation; intended to reflect generally slow vehicle movement.

TABLE 5-3. MEAN WIND SPEED[a] [U] FOR SELECTED UNITED STATES STATIONS

Station	State	[U] (m/s)	Station	State	[U] (m/s)
Birmingham	AL	3.3	Detroit	MI	4.6
Montgomery	AL	3.0	Grand Rapids	MI	4.5
Tucson	AZ	3.7	Lansing	MI	4.6
Yuma	AZ	3.5	Sault St. Marie	MI	4.3
Fort Smith	AR	3.4	Duluth	MN	5.1
Little Rock	AR	3.6	Minneapolis	MN	4.7
Fresno	CA	2.8	Jackson	MS	3.4
Red Bluff	CA	3.9	Columbia	MO	4.4
Sacramento	CA	3.7	Kansas City	MO	4.6
San Diego	CA	3.0	St. Louis	MO	4.2
Denver	CO	4.1	Springfield	MO	5.0
Grand Junction	CO	3.6	Billings	MT	5.1
Pueblo	CO	3.9	Great Falls	MT	5.9
Hartford	CT	4.0	Havre	MT	4.5
Washington	DC	3.4	Helena	MT	3.5
Jacksonville	FL	3.8	Missoula	MT	2.7
Tampa	FL	3.9	North Platte	NE	4.6
Atlanta	GA	4.1	Omaha	NE	4.8
Macon	GA	3.5	Valentine	NE	4.8
Savannah	GA	3.6	Ely	NV	4.7
Boise	ID	4.0	Las Vegas	NV	4.0
Pocatello	ID	4.6	Reno	NV	2.9
Chicago	IL	4.6	Winnemucca	NV	3.5
Moline	IL	4.4	Concord	NH	3.0
Peoria	IL	4.6	Albuquerque	NM	4.0
Springfield	IL	5.1	Roswell	NM	4.1
Evansville	IN	3.7	Albany	NY	4.0
Fort Wayne	IN	4.6	Binghamptom	NY	4.6
Indianapolis	IN	4.3	Buffalo	NY	5.5
Burlington	IA	4.6	New York	Ny	5.5
Des Moines	IA	5.0	Rochester	NY	4.3
Sioux City	IA	4.9	Syracuse	NY	4.4
Concordia	KS	5.4	Cape Hatteras	NC	5.1
Dodge City	KS	6.3	Charlotte	NC	3.4
Topeka	KS	4.6	Greensboro	NC	3.4
Wichita	KS	5.6	Wilmington	NC	4.0
Louisville	KY	3.8	Bismarck	ND	4.7
Shreveport	LA	3.9	Fargo	ND	5.7
Portland	ME	3.9	Cleveland	OH	4.8
Baltimore	MD	4.2	Columbus	OH	3.9
Boston	MA	5.6	Dayton	OH	4.6
Toledo	OH	4.2	Dallas	TX	4.9

(continued)

TABLE 5-3 (continued)

Station	State	[U] (m/s)	Station	State	[U] (m/s)
Oklahoma City	OK	5.7	El Paso	TX	4.2
Tulsa	OK	4.7	Port Arthur	TX	4.5
Portland	OR	3.5	San Antonio	TX	4.2
Harrisburg	PA	3.4	Salt Lake City	UT	3.9
Philadelphia	PA	4.3	Burlington	VT	3.9
Pittsburgh	PA	4.2	Lynchburg	VA	3.5
Scranton	PA	3.8	Norfolk	VA	4.7
Huron	SD	5.3	Richmond	VA	3.4
Rapid City	SD	5.0	Quillayute	WA	3.0
Chattanooga	TN	2.8	Seattle	WA	4.1
Knoxville	TN	3.3	Spokane	WA	3.9
Memphis	TN	4.1	Green Bay	WI	4.6
Nashville	TN	3.6	Madison	WI	4.4
Abilene	TX	5.4	Milwaukee	WI	5.3
Amarillo	TX	6.1	Cheyenne	WY	5.9
Austin	TX	4.2	Lander	WY	3.1
Brownsville	TX	5.3	Sheridan	WY	3.6
Corpus Christi	TX	5.4	Elkins	WV	2.8

Source: Adapted from *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, EPA/600/8-85/002, U.S. EPA, Office of Health and Environmental Assessment, Washington, DC.

[a] Data taken from *Local Climatological Data - Annual Summaries for 1977*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration/Environmental Data Service/National Climatic Data Center.

5.2.2 Level of Contamination

The data presented in Reference 1 suggest several points that may be useful in specifying the level of contamination (α) for landfill units. These include:

- The question of whether or not a given organic compound is present and if so at what levels is far more site-specific for organics than for RCRA metals. This suggests that source-specific S&A would, in fact, be needed to characterize α levels for organic compounds.
- If a source-specific S&A plan is being developed (see Appendix D for generic procedures), the data in Reference 1 indicate that organic compounds with lower vapor pressures tend to be found more often than compounds with high vapor pressures (i.e., volatile compounds). As a result then, the S&A plan should be directed toward organic compounds with relatively low vapor pressures (< 10 mm Hg).
- For off-site facilities, the available data indicate that all the RCRA metals (with the possible exceptions of silver [Ag] and selenium [Se]) typically are present at levels in excess of background values. Thus, source-specific S&A generally should not be required to establish which metals are present, but only to determine what are representative α levels.
- As an alternative to source-specific S&A for metals, a "worst-case" scenario could be developed based on the data shown in Table 5-4. For example, this could be accomplished by taking the maximum values (upper end of the range) and applying a "safety factor" of 5 or 10. In other words, multiply the upper end values by 5 or 10 as a conservatively high estimate of α.

5.3 CONTROL TECHNIQUES

While there has been no actual field testing of particulate control techniques at HW TSDFs, for "first-cut" analyses, it is reasonable to assume that much of the experience and information developed in more traditional industries (e.g., iron and steel) can be applied to HW TSDFs.

TABLE 5-4. SUMMARY OF RCRA METALS CONCENTRATION (μg/g)[a,b,c]

RCRA metal	$\bar{x}$[d]	Range
Arsenic (As)	12.7	4.7-21.3
Barium (Ba)	771	86.9-3,340
Cadmium (Cd)	35.8	ND[e]-150
Chromium (Cr)	1,200	91.2-1,500
Lead (Pb)	1,490	54.4-6,870
Mercury (Hg)	1.7	ND-9.75
Selenium (Se)	1.5	ND-4.80
Silver (Hg)	13.2	ND-46.4

[a] Data taken from Reference 1.

[b] At some facility units, more than one sample was analyzed; in this case the mean value for the unit is used to compute the overall mean shown.

[c] Statistics based on samples collected from 8 different landfill cells.

[d] Refers to arithmetic mean; nondetected values assumed to be equal to 0.0.

[e] ND refers to not detected.

This section discusses the use of both mitigative controls typical of traditional heavy industry, as well as preventive controls potentially applicable to HW landfill units.

5.3.1 Preventive Controls

As applied to HW landfills, preventive controls might be more appropriately termed "good operational practices." For HW loadout (unit operation I), the principal preventive control would involve use of containers, including double bags, shrink wrapping, drums, etc., to reduce the potential for finely divided materials to become entrained into the atmosphere during the loadout operation.

The emission factor relationship to be used for waste loadout indicates that emissions are expected to vary inversely with moisture content of the material. This suggests that addition of moisture to the waste stream prior to loadout could be a feasible control. However, this control cannot be generally recommended to cover all waste streams and sites because it may contradict guidance designed to minimize leachate production from the unit. In other words, the decision as to whether or not moisture is added must be made on both site- and waste stream-specific bases.

For the unit operation involving loadout of temporary cover, it is assumed that the cover material is uncontaminated, and thus only gross particulate emissions would be of concern. Reductions in the volume of material and/or addition of moisture would be expected to reduce gross emissions associated with this operation. In practice, however, reducing cover material may lead to situations where contaminated material is inadequately covered, thereby increasing the potential for contaminated particulate emissions. For this reason, the feasibility of reducing cover material must be evaluated on a unit-specific basis.

For the unit operation of lift construction and maintenance, practices vary widely from facility to facility. Despite this variation, the use of *dedicated* landfill equipment is a preventive control practice that should be applicable at almost all facilities. The term "dedicated" means simply that a given piece of landfill equipment (e.g., bulldozer) operates only within the landfill unit and is not routinely removed from the landfill to perform other facility activities. The rationale for this practice is simply that restricting the movement of the landfill equipment, in effect, decreases the likelihood that contaminated material will be spread over other facility travel surfaces. To control material spreading when dedicated equipment must be removed from the landfill unit--periodic maintenance, for example--a wash station should be established.

Another potential mitigative practice for contaminated particulate involves "housekeeping" on travel surfaces proximate to the landfill face. Housekeeping refers to the use of a scraper or motor grader to remove contaminated material that may be deposited in travel areas during normal lift construction. Again, this practice is intended to reduce the spreading of contaminated material.

For the unit operation encompassing general vehicle traffic, preventive control may be initiated by construction of temporary roadways with gravel or other aggregate material. The replacement of a travel surface with relatively coarse aggregate reduces silt content and thus particulate emissions. In control of contaminated particulate, this practice is intended mainly to aid *traffic routing*. The objective is to restrict general traffic to areas that are not used actively by operating landfill equipment. Separating the activity patterns of operating equipment from other vehicles may potentially reduce the spread and subsequent reentrainment of contaminated material.

5.3.2 Mitigative Controls

As discussed in Section 2.2.3.2, there are various mitigative measures that potentially could be used to control particulate emissions from operating landfill units. These measures fall under the category of surface treatments and include watering as well as chemical stabilization. Chemical suppressants should be evaluated on a unit-specific basis, with particular attention paid to compaction of the surface, drainage, suppressant composition, etc.

Watering as a control measure for landfill operations does not appear to suffer from the same limitations as chemical suppressants. That is, water alone presumably would not markedly increase the levels of undesirable organic compounds added to the landfill surface. (Note that leachate production due to frequent watering may be a concern; this is discussed below.) Similarly, curing time and its impact on operations is not a relevant concern as it may be with chemical suppressants. The central issues in determining whether or not water represents a feasible control at landfills involve:

- Application intensity (see Section 2.2.4.3).
- Frequency of application (see Section 2.2.4.3).
- Indirectly the potential spreading of contaminated material due to trackout.
- Climatic conditions.

As discussed in Section 2.2.4.3, available field data indicate that while application intensity (i.e., amount of water applied per unit area) directly influences particulate control efficiency, the relationship probably is not linear (cf. Eq. 2-11). The long-term level of control for a given average intensity can depend, for example, on activity levels, climate, antecedent surface conditions, etc. The relationship between frequency of application and control may be assumed to depend on essentially the same factors.

In a qualitative sense, low application intensities and infrequent applications generally may provide little effective control. On the other hand, high intensities/frequency may create undesirable results in terms of both contaminated particulate control as well as ground- and surface-water quality. More specifically, addition of excess water either directly to the bulk waste material or to the landfill surface could result in:

- Reduction in the structural integrity of the lift material.
- Increases in leachate volume.
- Increase in the amount of contaminated material spread to surrounding areas.

Each of the above represents an undesirable condition that has long-term implications for the proper management of the landfill unit. For this reason, like chemical dust suppressants, use of water should be recommended on a unit-specific basis. If it can be demonstrated that a watering program does not produce undesirable "side effects" (i.e., the points noted above), estimated control efficiencies can be developed by extrapolating the bilinear relationship cited in Section 2.2.4.3 to cover the variety of activities common to landfills. For convenience, this bilinear relationship is reiterated below.

$$c = \begin{cases} 75\ (M - 1) & 1 \leq M < 2 \\ 62 + 6.7\ M & 2 \leq M \leq 5 \end{cases} \qquad (5\text{-}2)$$

where: c = instantaneous control efficiency, %
M = ratio of controlled to uncontrolled surface moisture contents

Note that this approach requires data on controlled and uncontrolled surface moisture contents. A potential format for producing this information is outlined in Section 5.5.2.

5.4 CONTROL PERFORMANCE ESTIMATION

Most of the control measures identified above as appropriate for landfill operations involve the reduction of source extent. The control efficiencies to be achieved are predictable in that emissions are directly proportional to source extent. Therefore, the control efficiency value, as a percentage of uncontrolled emissions, is numerically equal to the percentage of source extent reduction. The control efficiency value would apply both to gross and contaminated emissions alike.

In the case of containerizing the hazardous waste to reduce dust emissions during loadout, a high efficiency of control (i.e., exceeding 90%) would be expected. This assumes that container integrity is maintained during transport of waste to the site and during the waste dumping.

In the case of general vehicle traffic, the control efficiency obtained through the use of coarse aggregate for temporary roadways is predictable based on the decrease in road surface silt content achieved. In the case of contaminated particulate emissions, adjustment of the control efficiency for gross particulate emissions would have to be made to reflect any difference between the surface silt contamination level with and without the surface improvement in place.

5.5 PROCEDURES FOR COMPLIANCE DETERMINATION

The regulatory approach to control particulate emissions from landfills is by definition predicated on the RCRA site-specific permit system. Control agencies would issue construction, operation, and use permits to facility operators. In this section it is assumed that permits specify a set of conditions or activities that must be provided or undertaken by the source to ensure that PM_{10} emissions are kept to acceptable levels. Compliance determinations for landfill units will then involve field observations/audits, as well as inspection of control implementation records. Additionally, compliance monitoring may require collection and analysis of surface samples of dust-emitting material using the procedures outlined in Appendix D.

5.5.1 Preventive Controls

Field observations are the principal basis for determining whether or not the preventive controls cited as permit conditions are in fact being followed. Table 5-5 provides an example checklist form for audits of landfill preventive control practices. There are several points concerning the checklist that should be noted including:

1. The length of time for field observation/audit as well as audit frequency should be sufficient to view "typical" operations. While this certainly will vary from unit to unit, 1- to 2-day unannounced audits conducted twice annually can be recommended as a *minimum* program.
2. To the extent possible, the audits should not be scheduled in advance, so that a "clear picture" of typical practices is obtained rather than one potentially biased by advance notice.
3. In checking temporary cover, the objective is to look at that position of the landfill unit that was used on the day preceding the audit since most permits require "daily cover to a specified depth."

TABLE 5-5. EXAMPLE OBSERVATION/AUDIT CHECKLIST FOR LANDFILL PREVENTIVE CONTROL PRACTICES

1. Date:

2. Observation time(s):

	Yes	No
3. Is there evidence that dedicated landfill equipment is leaving the landfill unit?		
4. Is equipment rinse station operational?		
5. Is there evidence of waste containers being ruptured during handling and/or placement into the landfill unit?		
6. Is the desired traffic routing pattern (for waste haulers) clearly marked?		
7. Is there evidence that waste and/or temporary cover haulers are traveling over deposited waste material?		
8. Is a motor grader in use for "housekeeping"?		
9. Is depth and amount of temporary cover sufficient to minimize exposure to previously deposited waste material? Note: This should be determined for an area that has been used immediately prior to field audit		

Inspection of records is a necessary complement to the audit/observation checklist. For example, as indicated in Section 5.3, site operators must remove dedicated equipment from the landfill unit for periodic maintenance. Maintenance records are routinely kept for heavy equipment. Site operators should be required to provide corresponding documentation to indicate that the equipment has been thoroughly washed prior to its removal from the landfill area.

As indicated in Sections 5.3 and 5.4, construction of temporary roadways using coarse aggregate is a recommended technique for reducing particulate emissions. At the same time, it is useful in clearly defining the traffic routes that are desired to minimize the spreading of waste material. If gravel is used as a preventive control, the operator should be required to document the following items:

1. Type of gravel purchased, delivery dates, and quantities (tons)
2. Quantity stockpiled on-site at time of delivery (excluding current purchase)
3. Estimate of the material bulk density (lb/yd^3)
4. Application dates
5. Area treated (length and width)
6. Nominal depth of application (in)
7. Site map showing road orientation after each application
8. Any marking precautions (such as barrels, rope, pennants, etc.)

The purpose of this information is to allow the field inspector to perform a "rough" mass balance. That is, the following expression should be verifiable:

Total quantity applied (tons) = total material purchased (tons) -
total material stockpiled (tons)

Two points should be noted here:

1. The quantity stockpiled refers to the amount of material stockpiled on-site at the time of *each* delivery, exclusive of the delivered material itself. Thus, each delivery should have a corresponding stockpile value.

2. Based on the estimated bulk density, area treated, and depth, the inspector can approximate the quantity applied (tons) in each application. The sum of these individual values then becomes the total quantity applied.

5.5.2 Mitigative Controls

Watering is the principal mitigative control anticipated for use in landfill units. As indicated in Section 5.5.1, determining the control efficiency associated with watering requires uncontrolled and controlled values of surface moisture content. If watering is being used as a control, the required data can be obtained during the field audits (specified under Section 5.5.1).

Generic procedures for collection of surface samples and for moisture content analyses are given in Appendix D. The uncontrolled sample(s) should be taken early in the morning before the first water application. The controlled sample(s) should be taken at the approximate midpoint in time between successive applications. For example, if the facility routinely applies water at 2-h intervals, the control moisture sample should be taken after 1 h. For purposes of this watering evaluation, it is critical that the application intensity (i.e., amount/unit area) and frequency be the same as that used under "typical" operating conditions.

In order to verify that the watering done during the evaluation constitutes typical practice, the facility operator must specify the parameters of the control plan and make provisions to document the fact that the plan is being followed. The parameters to be specified in the plan and to be regularly recorded are comparable to those for unpaved roads. They include:

General Information

1. Area to be treated
2. Amount of water applied to each road/area and planned frequency of application (alternatively, a minimum moisture level could be specified)

3. Any provisions for weather (e.g., 1/4-in of rainfall with be substituted for one treatment; program suspended during freezing periods; watering frequency as a function of temperature, cloud cover, etc.)
4. Source of water and tank capacity

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment
2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets)
3. Start and stop times in a particular area, average speed, number of passes
4. Start and stop times for tank filling

General Records

1. Equipment maintenance records
2. Meteorological log (to the extent that weather influences the control program, see above)
3. Any equipment malfunctions or downtime

5.6 EXAMPLE CALCULATION

An example application of the emission estimation procedures for landfill units is presented below. This example focuses on contaminant-specific (i.e., lead) emissions, but the procedures would be essentially the same for gross particulate emissions.

The example landfill unit is taken as an off-site facility located in a semiarid climate with a mean annual wind speed of 3 m/s and 320 dry d/yr. The facility operates 5 d/wk (261 d/yr) and accepts the following listed waste streams likely to contain appreciable concentrations of lead (Pb).

Waste Stream	Annual Receipts (Mg)
K061	5,000
K052	100
K002	15

Based on waste manifests and information supplied by the facility operators, pertinent characteristics of waste streams are specified as:

Waste Stream	Pb Concentration (ppm)	Silt Content (%)	Moisture Content (%)
K061	3,000	30	1
K052	1,500	8	20
K002	300	8	20

Because the specified Pb concentrations are based on waste manifests and information supplied by the facility, the values given above incorporate a "safety factor' of 5, in accordance with the approach indicated in Section 5.2.2. These Pb concentrations are applicable to loadout of the raw wastestreams (unit operation I; see Eq. 5-1 of Table 5-1). Because no site-specific S&A is undertaken, the conservative assumption is made that the Pb concentrations for surfaces subject to dozer activity and to vehicle traffic are equal to the highest volume (K061) "raw" waste stream levels (incorporating the safety factor of 5). Default values for silt and moisture content (averages presented in Table 5-2) are assumed applicable to lift construction (unit operation III) and to general vehicle traffic (unit operation IV).

Based on site observations and conversations with facility personnel, annual source extent parameters are estimated as follows:

Unit operation I--(annual receipts above);

Unit operation II--(clean cover containing negligible concentrations of Pb);

Unit operation III--1,566 h (one dozer operating ~ 6 h/d); and

Unit operation IV--260 VKT (50 vehicles/d traveling ~ 20 m round trip in the area proximate to the landfill face).

For unit operation I--receipt/loadout of wastes--the uncontrolled emission rate is calculated from Eq. 5-1 (see Table 5-1) which can be expressed as:

$$e_{Pb} = \alpha \cdot (0.00056) \cdot \left(\frac{U}{2.2}\right)^{1.3} / \left(\frac{M}{2}\right)^{1.4} \cdot \text{(source extent)} .$$

It is simplest to perform the calculations for individual waste streams so that for K061:

$$e_{Pb} = \frac{3,000}{1.0E6} \cdot (0.00056) \cdot \left(\frac{3.0}{2.2}\right)^{1.3} / \left(\frac{1}{2}\right)^{1.4} \cdot 5,000 = 0.03318 \text{ kg} ;$$

for K052:

$$e_{Pb} = \frac{1,500}{1.0E6} \cdot (0.00056) \cdot \left(\frac{3.0}{2.2}\right)^{1.3} / \left(\frac{20}{2}\right)^{1.4} \cdot 100 = 5.0E\text{-}6 \text{ kg} ;$$

Uncontrolled Emission Rates

for K002:

$$e_{Pb} = \frac{300}{1.0E6} \cdot (0.00056) \cdot \left(\frac{3.0}{2.2}\right)^{1.3} / \left(\frac{20}{2}\right)^{1.4} \cdot 15 = 1.5E\text{-}7 \text{ kg} .$$

The total estimated Pb emissions from unit operation I are then given as:

$$e_I = e_{K061} + e_{052} + e_{K002} = 0.0332 \text{ kg} .$$

For unit operation II, Pb emissions are assumed negligible because the temporary cover material is specified as "clean" or uncontaminated.

For unit operation III--dozer activity--the emission rate is calculated from Eq. 5-2 (see Table 5-1) which can be expressed as:

$$e_{Pb} = \alpha \cdot 0.34 \cdot (s)^{1.5} / (M)^{1.4} \cdot (\text{source extent}) .$$

Given the specifications for source extent and α levels, the emission rate is given by:

$$e_{pb} = \frac{3,000}{1.0E6} \cdot 0.34 \cdot (12.7)^{1.5} / (19.6)^{1.4} \cdot 1,566 \text{ ; or}$$

$$e_{III} = 1.12 \text{ kg}$$

For unit operation IV--vehicle traffic--the emission rate is calculated from Eq. 5-3 which can be expressed as:

$$e_{Pb} = \alpha\, (0.61) \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-45}{365}\right) \cdot (\text{source extent}) .$$

Given the specifications for source extent and α levels, the emission rate is then:

$$e_{pb} = \frac{3,000}{1.0E6}\,(0.61)\left(\frac{8}{12}\right)\left(\frac{8}{48}\right)\left(\frac{20}{2.7}\right)^{0.7}\left(\frac{12}{4}\right)^{0.5}\left(\frac{320}{365}\right)\cdot 260\ ;\ \text{or}$$

$$e_{IV} = 0.326\ \text{kg}\ .$$

Total Pb emissions from the landfill unit, then, are estimated as the sum of values for the individual unit operations. That is:

$$e_I + e_{II} + e_{III} + e_{IV} = 0.0332 + - 0 + 1.12 + 0.326;\ \text{or}$$

$$= 1.48\ \text{kg}\ .$$

Thus it is estimated that 1.48 kg of lead is emitted annually due to landfill operations.

Specification of Dust Control Program

Suppose that it is determined that the Pb emission rate for the landfill unit must be reduced to an annual value of less than 1 Kg. This result could be indicated for example by the application and results of the risk assessment methodology presented in Appendix C. Given the relative contribution of each of the unit operations to the total uncontrolled Pb emission rate (i.e., the uncontrolled calculations cited above) it is apparent that emissions associated with dozer activity (unit operation III) contribute the largest fraction to the total rate. In this sense, it is logical to first examine controls for this activity.

As indicated in Section 5.3.2, water may be considered as a control measure for landfill units on a site-specific basis subject to demonstration that it does not produce undesirable "side effects" (e.g., reduction in structural integrity of the lift material). Both the raw wastestream moisture content values and the default moisture content for surface material disturbed by dozer activity (19.6% from Table 5-2) are relatively high. This suggests that application of additional water would not be practical in this example. The most easily implemented control for dozer activity is simple source extent reduction; in effect, this control represents a change in operating practice. In the equation for estimating emissions associated with dozer activity, the emission rate is directly proportional to the number of hours per day (source extent) that the vehicle operates on the lift, i.e.,

$$e = \frac{0.34(s)^{1.5}}{(M)^{1.4}} \text{ x source extent;}$$

where s refers to silt content and M to the moisture content of the disturbed waste and cover material. Assuming no change in physical characteristics, reduction of source extent from 6 h (in the uncontrolled case) to 3 h (as a control) represents a control efficiency (CE) of 50% (i.e., a reduction by one-half). Application of this CE in the emission factor model produces a corresponding reduction in emission rate as shown below.

$$\begin{aligned} e_{\text{Pb (controlled)}} &= \alpha \cdot 0.34 \cdot (s)^{1.5} / (M)^{1.4} \cdot (1 - \frac{CE}{100\%}) \\ &= \frac{3{,}000}{1.0E6} \cdot 0.34 \cdot (12.7)^{1.5} / (19.6)^{1.4} \cdot (0.50 \\ &= 0.56 \text{ Kg} \end{aligned}$$

Combining the above result (for unit operation III--dozer activity) with uncontrolled values for unit operations I (loadout of bulk hazardous materials), II (loadout of cover), and IV (general vehicle traffic) produces a total annual Pb emission rate as follows:

$$\begin{aligned} e_I + e_{II} + e_{III} + e_{IV} &= 0.0332 + {}^{-}\, 0 + 0.50 + 0.326 \\ &= 0.859 \text{ Kg} \end{aligned}$$

Thus, the total Pb emission rate with source extent reduction for dozer activity produces the required decrease in estimated annual emission rate.

5.7 REFERENCES FOR SECTION 5

1. Englehart, P., and D. Wallace. Assessment of Hazardous Waste TSDF Particulate Emissions. Final Report, EPA Contract No. 68-02-3891, Assignments 5 and 13, U.S. Environmental Protection Agency, Research Triangle Park, NC. October 1986.

2. Environmental Protection Agency. Compilation of Air Pollution Emission Factors (AP-42). Research Triangle Park, NC. September 1988.

3. Muleski, G., and D. Hecht. PM_{10} Emission Inventory of Landfills in the Lake Calumet Area. Final Report, EPA Contract No. 68-02-3891, Work Assignment 30. September 1987.

4. Muleski, G., F. Pendleton, and D. Hecht. Chicago Area Particulate Matter Emission Inventory--Sampling and Analysis. Final Report, EPA Contract No. 68-02-4395, Work Assignment 1. May 1988.

6.0 LAND TREATMENT

6.1 SOURCE DESCRIPTION

Unlike disposal practices at hazardous waste landfills which have not been studied extensively, a large body of literature is available concerning various facets of land treatment of industrial wastes.[1-2] The American Petroleum Institute (API) has done extensive work on performance of land treatment systems for refinery wastes.[3-4] API describes land treatment as a managed technology that involves the controlled application of a waste on the soil surface, followed by incorporation of the waste into the upper soil zone. The objectives of the land treatment process are to degrade, immobilize, or transform the constituents of the applied waste into environmentally acceptable components.

The size (treatment area) and physical configuration of these units will, of course, vary from facility to facility and may depend upon factors such as:

- Land availability.
- Waste stream physical and chemical characteristics.
- Disposal schedule and waste volume.
- Soil characteristics.
- Climate.

Table 6-1 presents "model plant" size distributions developed by the U.S. EPA.[5]

Physical configurations for land treatment units may be divided into three broad categories--single plot, progressive plot, and rotating plot. These categories are depicted in Figure 6-1. In design terms, a single plot configuration is one in which the treatment area is not subdivided, so that the waste is spread "uniformly" over the available area. This approach is considered feasible when applications are made only during one season of the year, or on only a few specific occasions. A progressive plot configuration is one in which the treatment area is subdivided into smaller cells, with one or more of the cells designated as active and the remaining cells as inactive or "fallow." The latter may be vegetated. The rotating plot configuration involves subdivision of the treatment area into plots which are then loaded sequentially; that is, all plots may be considered active and application of waste is made at intervals judged sufficient to achieve the desired treatment effect(s).

TABLE 6-1. MODEL PLANT SIZE DISTRIBUTIONS FOR LAND TREATMENT UNITS

	Land treatment size distributions					
	Surface area (m^2)					
	Minimum	20th Percentile	50th Percentile	80th Percentile	Maximum	No. in sample
On-site	180	14,000	54,000	1.5×10^5	7.6×10^5	34
Off-site	20,000	40,000	81,000	1.2×10^5	4.0×10^5	8
Overall	180	16,000	57,000	1.4×10^5	7.6×10^5	42

All land treatment operations can be viewed as involving two principal activities: (1) waste application followed by (2) incorporation and subsequent cultivation. Additionally, some facilities practice soil amendment (adding agricultural lime or commercial fertilizers to aid the treatment processes).

The waste application practices, including frequency of application, employed at a specific facility have likely evolved to account for the factors cited above. Field observations suggest that choice of application method probably depends largely on waste stream physical characteristics (i.e., land availability, waste stream characteristics, etc.). In cases where the waste streams are "fluid" or pumpable, a vacuum truck equipped with a delivery system (hose, spray bar, etc.) may be the preferred application system. A variation on this approach involves an intermediate step in which the waste is first transferred from the vacuum truck to a conventional liquid manure spreader. The spreader is attached to a tractor and then pulled across the treatment plot.

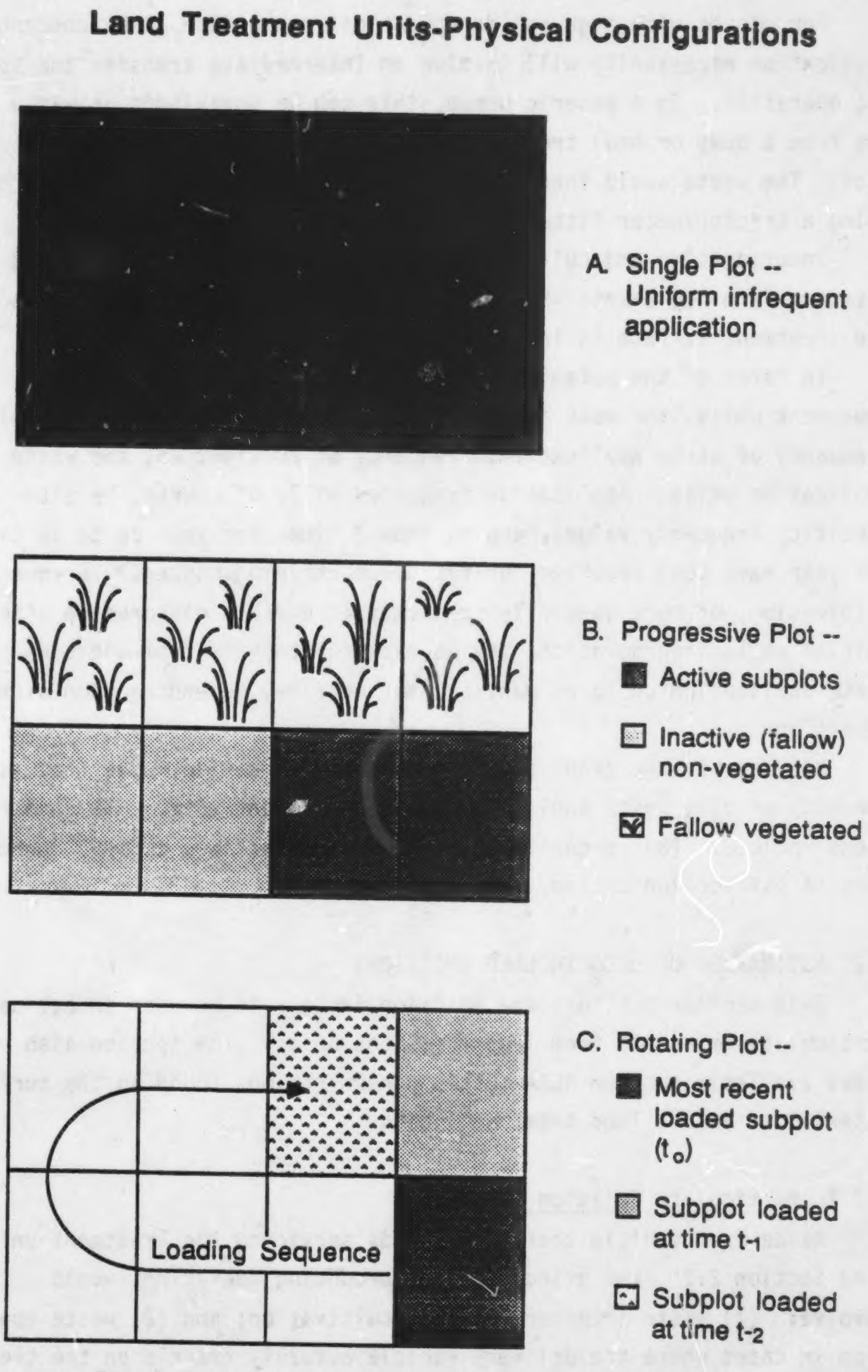

Land Treatment Units-Physical Configurations
A. Single Plot -- Uniform infrequent application
B. Progressive Plot --
Active subplots
Inactive (fallow) non-vegetated
Fallow vegetated
C. Rotating Plot --
Most recent loaded subplot (t_o)
Subplot loaded at time t_{-1}
Subplot loaded at time t_{-2}
Loading Sequence

Figure 6-1. Land treatment units--physical configurations.

For wastes with high solids and/or oil and grease (O&G) content, application necessarily will involve an intermediate transfer and spreading operation. In a generic sense, this can be envisioned as waste loadout from a dump or haul truck onto a small portion of the treatment plot. The waste would then be spread evenly across a designated area using a tractor/dozer fitted with a blade.

Incorporation and cultivation typically are accomplished using standard farm implements--harrows, plows, rototillers. Cultivation of the treatment surface is intended to promote soil aeration.

In terms of the potential for particulate emissions from land treatment units, the most important operating parameters are probably frequency of waste application, frequency of cultivation, and waste application rates. Application frequency will, of course, be site-specific; frequency values ranging from 2 times per year up to 52 times per year have been reported for petroleum refining wastes.[3] Frequency of cultivation, or more generally frequency of surface disturbance after initial waste incorporation, may be expected to vary from one time per waste application up to as many as four or five, depending upon site conditions.

Many terms have been used to identify application rate, that is, the quantity of oily waste applied to a land treatment site. Common definitions include: (a) percent oil in the soil/unit time, and (b) barrels or tons of oil/acre/unit time.[3]

6.2 ESTIMATION OF UNCONTROLLED EMISSIONS

This section outlines the emission factors to be used in estimating particulate emissions from land treatment units. The section also provides available data on RCRA metals concentrations found in the surface material at active land treatment units.

6.2.1 Particulate Emission Rates

Aside from vehicle traffic on roads servicing the treatment unit (see Section 2.2), the principal dust producing operations would involve: (1) waste incorporation and cultivation; and (2) waste application in cases where the delivery vehicle actually travels on the treatment surface. Under certain conditions, wind erosion from the treatment surface may constitute a third potential dust-emitting mechanism. However, this contribution can be expected to be negligible in comparison with emissions generated by mechanical activities.

The emission factors for incorporation and cultivation is as follows:

$$e = k(5.38)(s)^{0.6} \quad \text{kg/ha} \qquad (6\text{-}1)$$

$$e = k(4.80)(s)^{0.6} \quad \text{lb/acre}$$

where:
e = PM_{10} emission factor in stated units of treated surface area
k = particle size multiplier = 0.21 for PM_{10}
s = silt content of the disturbed surface material (%)

For waste application the emission factor would correspond to travel on unpaved surfaces (see Section 2.2) and/or the dozer relationship (see Section 5.2.1) depending upon the specific nature of equipment used in the operation. These emission factor relationships are reiterated below.

For the case where the delivery vehicle travels on the treatment unit surface, the emission factors are:

$$e = 0.61 \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \text{ kg/VKT} \qquad (6\text{-}2)$$

$$e = 2.1 \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \text{ lb/VMT}$$

where:
e = PM_{10} emission factor in units stated
s = silt content of road surface material, %
S = mean vehicle speed, km/h (mi/h)

W = mean vehicle weight, Mg (ton)
w = mean number of wheels (dimensionless)
p = number of days with ≥ 0.254 mm (0.01 in) of precipitation

For the case where the higher solids content wastes are spread over the treatment area using a tractor/dozer fitted with a blade, the emission factors are:

$$e = \frac{0.34\ (s)^{1.5}}{(M)^{1.4}}\ \text{(kg/h)}$$

(6-3)

$$e = \frac{0.74\ (s)^{1.5}}{(M)^{1.4}}\ \text{(lb/h)}$$

where: e = PM_{10} emission factor in units stated
s = silt content (%) of the surface material
M = moisture content (%) of the surface material

In application of the incorporation and cultivation emission factor (Eq. 6-1) it is important to recognize the following features:

1. The emission factor is based on field source testing of a variety of agricultural operations including disking, harrowing, and land planing.[7] It is assumed that waste incorporation and cultivation generate particulate emissions at rates comparable to those found in the source testing.
2. In effect, the initial waste application probably should be thought of as a particulate control measure, the control effectiveness of which would decrease through time in a manner linked to the rate of decomposition of the waste material in the soil. At present, however, there is no information

available to specify the relationship between waste decomposition and particulate control efficiency. For this reason, it is recommended that any initial emissions calculations attribute zero control (i.e., uncontrolled) to the wastestream. If under this conservative assumption, a subsequent risk assessment indicates the potential for unacceptable risk levels, further in-depth analysis probably will be required. Generic requirements for this analysis are provided in Section 6.5.2.

Equation 6-1 requires only a single correction parameter--silt content of the disturbed material. Silt content values (determined according to the procedures given in Appendix D) for samples collected at three facilities treating refinery wastes, ranged from 2.0 to 11.3%. Implicit in the argument above concerning control efficiency versus waste decomposition, is the idea that silt content of the surface material also will vary as a function of time after waste application.

6.2.2 Level of Contamination (α)

Unlike many TSDFs, there are considerable data available to characterize α levels particularly in the case of RCRA metals for treatment units handling refinery wastes. Table 6-2 presents data compiled by the API for several active treatment units. For comparison, values based on the initial TSDF survey[6] also are included. Note that the latter units also were disposing of refinery wastes.

Specifications of α for organic compounds probably will require site-specific S&A (see Appendix D for generic procedures). Alternatively, information on the waste stream characteristics as supplied by facility operators may form the basis for worst-case estimates of α. In the latter case, it may be desirable to multiply waste stream concentrations by a safety factor of 5 to 10 in order to conservatively (i.e., overestimate) assign values of α for the treatment surface.

6.3 CONTROL TECHNIQUES

Although potential control measures for particulate emissions have not been evaluated under field conditions at specific land treatment

TABLE 6-2. SUMMARY OF RCRA METALS CONCENTRATIONS (ug/g) FOR LAND TREATMENT UNITS HANDLING REFINERY WASTES

Data source/parameter(s)	As	Cd	Cr	Pb	Hg	Ba	Se	Ag
API--Land Treatment Practices in the Petroleum Industry--June 1983								
Average[a]	2.76	5.11	277	718	2.11	-[b]	-	-
Range	0.41-16.3	0.11-10	1.5-1468	2.5-5560	0.04-11	-		
No. of individual plots sampled	15	23	30	30	23	-	-	-
No. of total samples collected	21	29	48	48	29	-	-	-
Hazardous Waste TSDF Survey (Ref. 6) 1985								
Arithmetic mean	15.3	ND[c]	222.0	129.0	2.16	220.5	2.0	4.1[d]
Range	6.6-52.6	ND[c]	90.6-658.0	33.0-483.0	0.85-7.22	106.0-319.0	0.5-4.2	ND-24.7
No. of individual plots sampled	5	5	5	5	5	5	5	5
No. of total samples collected	6	6	6	6	6	6	6	6

[a] Presumed arithmetic mean for samples taken at 0-1 ft depth.

[b] "-" refers to not reported.

[c] "ND" refers to not detected.

[d] Arithmetic mean calculated assuming not detected (ND) values with a concentration = 0.01 ug/g.

sites, observations of several active units suggest a number of alternatives for control. These options are discussed below.

6.3.1 Preventive Controls

As indicated in Section 6.1, the typical scope of operations at land treatment units is likely to be more limited than at landfill units. In this sense it probably is easier to envision how the implementation of preventive controls can produce emissions reductions, especially for contaminated material. Like the landfill case, the principal emphasis should be on source extent reduction--minimizing the spread of contaminated waste material from the treatment surface to unit service roads and adjacent areas.

A very basic preventive control involves design and implementation of features to control surface water runoff. The rationale here is that under inappropriate design, particulate removed from the treatment surface by high intensity rainfall events may tend to collect in areas subject to mechanical disturbance. In turn, this eroded material may constitute a significant source of contaminated particulate emissions.

A related simple control measure involves revegetation of fallow areas. This measure would provide effective wind and waste erosion control and could support at least intermittent vehicle traffic. The applicability of this control may be limited to progressive plot configurations.

Most preventive control measures for land treatment units are similar to those outlined for landfill units. For example, *dedicated* cultivation equipment should be required for land treatment units. A rinse station should be operated to clean equipment *prior* to removal for any periodic maintenance.

Other preventive controls include efforts to minimize travel of cultivation equipment on unit service roads. This measure is also applicable to any equipment used to spread higher solids content waste (e.g., dozer). Perhaps the most critical preventive control involves minimizing contact between the treatment surface and waste delivery vehicles. The rationale here is simply that a delivery vehicle generally cannot be restricted to the treatment unit area, and thus efforts to reduce contact with the treatment surface are required so that material will not be tracked out and deposited over all facility roadways.

A final preventive measure involves reducing the frequency of cultivation. This measure would in effect reduce source extent (i.e., area disturbed in Eq. 6-1), and thus linearly reduce calculated emissions. This approach might adversely affect waste treatment effectiveness, and thus the practice must be evaluated on a site-specific basis.

6.3.2 Mitigative Controls

Application of water probably is the only viable mitigative control for particulate emissions from land treatment surfaces. As indicated in Section 6.2.1, the initial waste application may be viewed as a mitigative control measure, the effectiveness of which would decrease through time in a manner linked to the rate of decomposition of the waste material. Following this argument, it is apparent that at some time after waste application, the treatment surface will in effect return to an essentially uncontrolled state.

If this time-dependent behavior can be specified (for a given facility), a watering program could then be instituted to control particulate for the time interval preceding another waste application. Alternatively, it might be more practical to simply reapply waste at the point in time where particulate control is considered to be effectively zero.

Note that use of a watering program for a land treatment unit should require a demonstration much like that cited in connection with landfills (see Section 5.3.2). That is, before instituting a watering program, the facility must demonstrate that addition of water to the treatment unit does not produce undesirable impacts on ground and surface water quality.

6.4 CONTROL PERFORMANCE ESTIMATION

A potentially applicable approach to specifying the time-dependent behavior of the waste material, and indirectly, its (waste) control effectiveness is outlined below. This approach involves the collection and analysis of surface samples using the S&A procedures outlined in Appendix D.

Figure 6-2 provides a schematic of the approach. In essence, it requires the collection of representative surface samples from:

1. The treatment surface.
2. A "background" area outside the treatment surface.

Note that the latter area should be chosen such that its physical and chemical properties are comparable to those of the treatment surface prior to any waste application.

Treatment surface and background samples should be collected at a minimum of two intervals (i.e., two points in time) between successive waste applications. The principal decision point in the procedure involves whether or not meaningful silt and moisture analyses can be performed (see Figure 6-2). Experience indicates that if O&G content in the treatment surface is relatively high, the material cannot be dry sieved using the procedures given in Appendix D. Thus silt content values needed for Eq. 6-1 would not be available. In this case, it is necessary to do O&G content analyses. Note that there are several procedures available to characterize O&G; because in the present context O&G data are used only as a relative measure, the important point is that the facility use a consistent and fully documented procedure to obtain this quantity.

In cases where the silt content can be obtained (a Yes decision in Figure 6-2), use of Eq. 6-1 provides estimates of the controlled emission rate. In cases where O&G content are performed (a No decision in Figure 6-2), estimates of control efficiency can be obtained using Figure 6-3. The latter estimates represent an extrapolation of the data cited in Section 2.4.3, to cover the cultivation operation.

6.5 PROCEDURES FOR COMPLIANCE DETERMINATION

This section assumes that RCRA permits specify a set of conditions or activities that must be provided or undertaken by the facility to ensure that PM_{10} emissions are kept to acceptable levels. Compliance determinations for land treatment units will then involve field observations/audits as well as inspection of control implementation records. Additionally, compliance monitoring may require collection and analysis

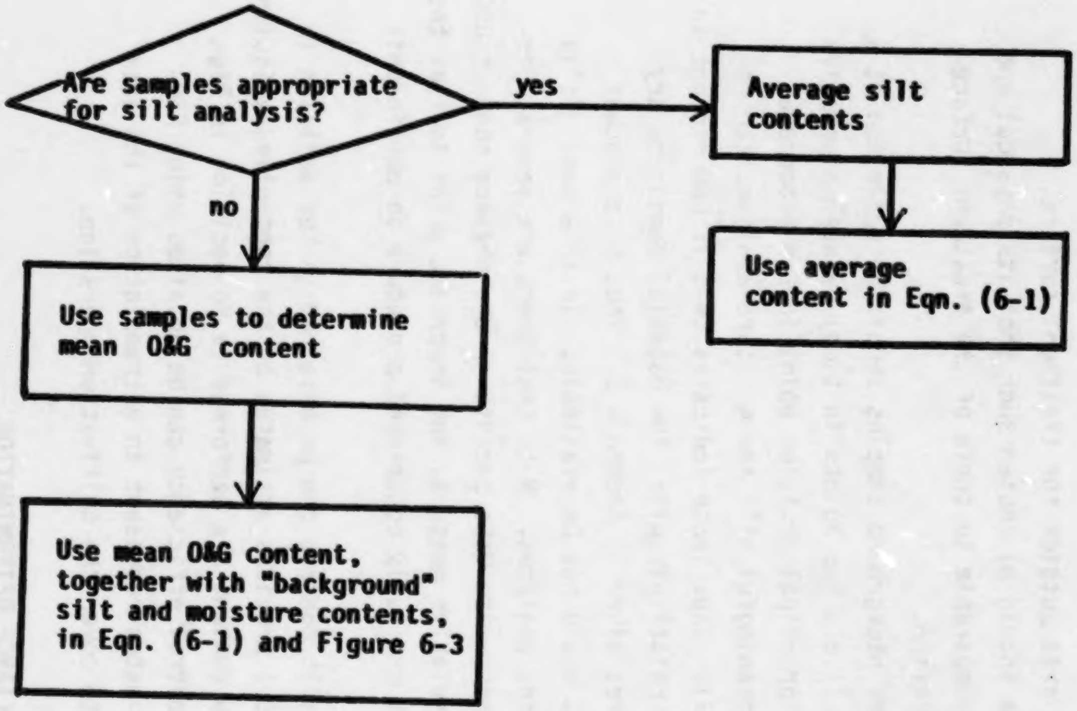

Are samples appropriate for silt analysis?
yes
no
Average silt contents
Use average content in Eqn. (6-1)
Use samples to determine mean O&G content
Use mean O&G content, together with "background" silt and moisture contents, in Eqn. (6-1) and Figure 6-3

Figure 6-2. Flowchart for evaluating control associated with waste application.

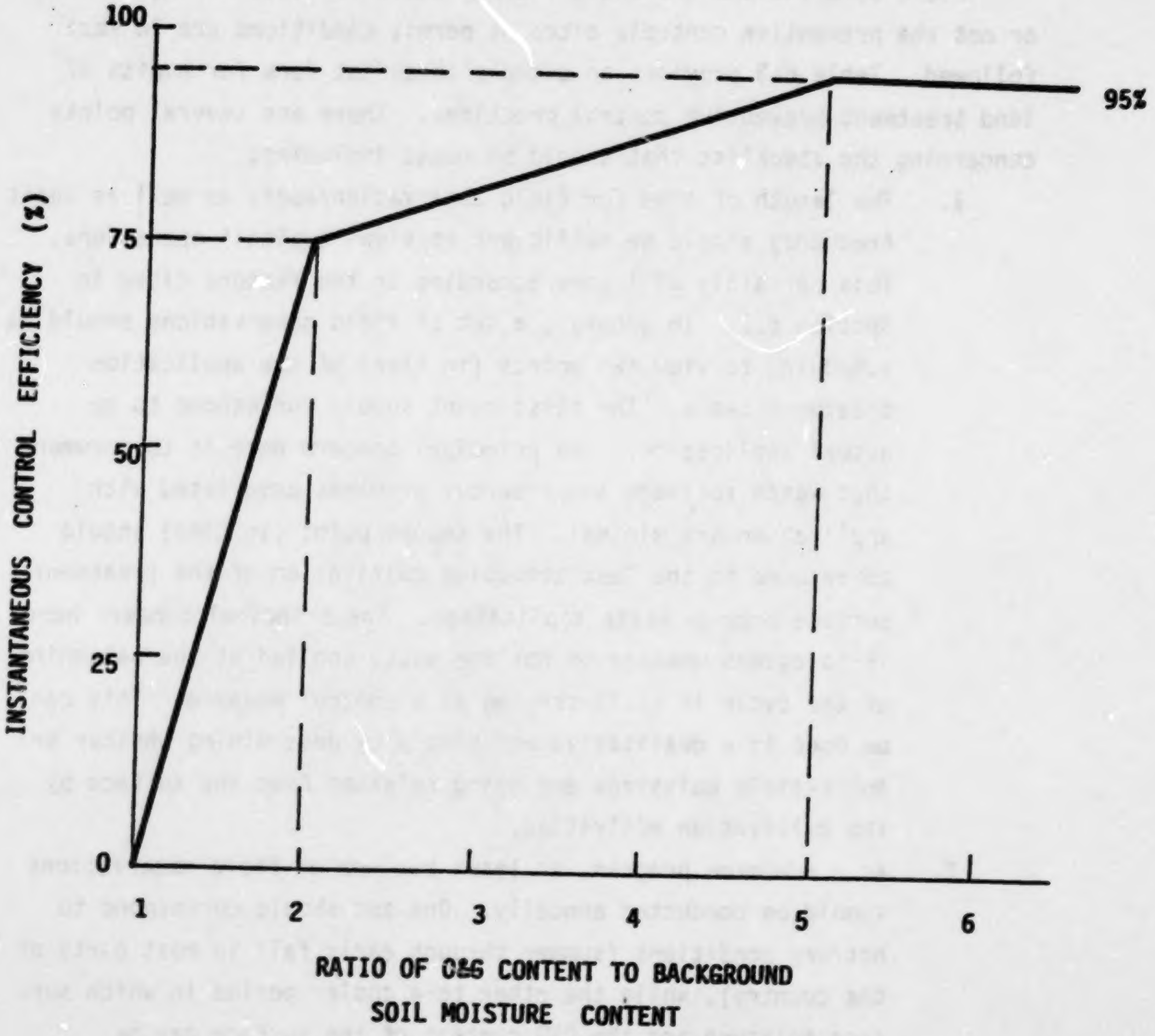


Figure 6-3. Procedure for estimating control efficiency with O&G content and moisture content measurements.

of surface samples of dust-emitting materials using the procedures outlined in Appendix D.

6.5.1 Preventive Controls

Field observations are the principal basis for determining whether or not the preventive controls cited as permit conditions are in fact followed. Table 6-3 provides an example checklist form for audits of land treatment preventive control practices. There are several points concerning the checklist that should be noted including:

1. The length of time for field observation/audit as well as audit frequency should be sufficient to view "typical" operations. This certainly will vary according to the factors cited in Section 6.1. In general, a set of field observations should be scheduled to view two points (in time) of the application treatment cycle. The first point should correspond to an actual application. The principal concern here is to document that waste spillage and trackout problems associated with application are minimal. The second point (in time) should correspond to the last scheduled cultivation of the treatment surface *prior to* waste application. The principal concern here is to assess whether or not the waste applied at the beginning of the cycle is still serving as a control measure. This can be done in a qualitative way simply by determining whether or not visible emissions are being released from the surface by the cultivation activities.
2. As a *minimum* program, at least *two sets* of field observations should be conducted annually. One set should correspond to hot/dry conditions (summer through early fall in most parts of the country), while the other to a cooler period in which surface moisture and the O&G content of the surface may be expected to remain high for longer time intervals.
3. To the extent possible, the field audits should not be scheduled in advance so that a "clear picture" of typical practices is obtained rather than one potentially biased by advance notice.

TABLE 6-3. EXAMPLE OBSERVATION/AUDIT CHECKLIST FOR LAND TREATMENT PREVENTIVE CONTROL PRACTICES

Application Point

1. Date: 2. Observation time(s)

Yes No

3. Is there evidence that dedicated equipment is leaving the treatment unit?
4. Is equipment rinse station operational?
5. Is there evidence of waste spillage and/or spreading of waste onto service roads?

Cultivation Point

6. Date: 7. Observation time(s)
8. Description of area treated:
9. Time since initial waste application __________
10. Time until next waste application __________
11. Number of observed passes with cultivation implements over the treatment surface __________
12. Are visible emissions generated by the cultivation activity?

6.5.2 Mitigative Controls

If under the conservative assumption of *no control* associated with waste treatment (i.e., as in Section 6.2.1), calculated risks due to particulate emissions are unacceptably high, development of site-specific data may be warranted. The objective here is to indirectly characterize the potential mitigative effects of waste stream addition *throughout the course of the typical waste treatment cycle*. Generic requirements for this approach are described below.

The unit operators must fully document the following items for a time period sufficiently long (~ 1 yr) to adequately characterize the expected range in unit operations:

- The date of each waste application.
- The type and amount of each waste stream applied to given treatment area.

Note that because a variety of terms are used to characterize application rate (see Section 6.1), the facility operators are required to provide conversion data so that data can be expressed as O&G (%) in the soil/unit time.

The above data defines length of the treatment cycle (t). At this point, the facility must demonstrate that for the maximum period (t_m) given in the documentation, cultivation produces no visible emissions. This will require field observation similar to that recommended under Section 6.5.1. Note that the field observations should not be made immediately after significant rainfall. If visible emissions are observed at t_m, a similar demonstration should be required for the interval $t_m/2$. The interval should be "halved" until the criterion of no visible emissions is met. In effect, based on the conservative criterion of no visible emissions, the above procedure provides a simple, qualitative way to establish the length of time over which waste application provides effective mitigative control.

Following this argument, the established cycle length represents the point at which the facility needs to institute a mitigative control measure. This mitigative control may simply be waste reapplication, or alternatively, a watering program could be instituted to cover the time period until waste reapplication.

It is important to recognize that the above approach addresses only risks associated with air emissions. It is possible that the cycle length (t) indicated by this approach may not be compatible with other requirements designed to safeguard ground and surface water quality.

6.6 EXAMPLE CALCULATION

An example application of the emissions estimation procedures for land treatment units is presented below. Note that this calculation uses the *no control* assumption discussed in Section 6.2.1.

The hypothetical unit is taken as a generator facility treating refinery wastes (K048,K051) and located in a continental climate. The facility operates a 6 hectare (~ 15 acres) treatment unit in a rotating plot configuration (six plots). Wastes are applied to each subplot at approximately 2 month intervals. A vacuum truck with spray bar is used for application; the subplots typically are cultivated four times after initial waste incorporation at approximately 2 week intervals.

Based on information supplied by the facility, it is determined that chromium (Cr) is the principal constituent of concern, and that Cr levels in the treatment surface can be conservatively (high) estimated at 4,000 ppm (µg/g). Note that this includes a safety factor of 5 as suggested for worst case estimates (see Section 6.2.2).

The annual source extent for the waste application operation is estimated as 120 vehicle kilometers traveled (VKT). This figure assumes a uniform 3-m spray pattern from the vacuum truck, and that the wastes are applied to square treatment plots at a frequency of once every 2 months. The annual source extent for cultivation is estimated at 144 hectare (ha) given four cultivation steps after initial waste incorporation. Note that it is assumed that each of the cultivation steps consists of a single pass over the plot(s).

The Cr emissions associated with waste application are given by the expression:

$$R_{Cr} = \alpha(0.61)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\ \text{(source extent)}$$

Inserting the appropriate values yields the expression:

$$R_{Cr} = \frac{4,000}{1.0E6} (0.61) \left(\frac{10}{12}\right) \left(\frac{8}{48}\right) \left(\frac{8}{2.7}\right)^{0.7} \left(\frac{10}{4}\right)^{0.5} (120)$$

Thus, Cr emissions for the application operation are estimated as 0.1375 kg.

The Cr emissions associated with cultivation are given by the expression:

$$R_{Cr} = \alpha(0.21) (5.38) (S)^{0.6} \text{ (source extent)}$$

Inserting the appropriate values yields the expression:

$$R_{Cr} = \frac{4,000}{1.0E6} (0.21) (5.38) (10)^{0.6} (144)$$

Thus, Cr emissions for the cultivation operation are estimated as 2.59 kg.

Total Cr emissions from the treatment unit (exclusive of service roads) is then estimated as the sum of the two unit operation values:

$$R_{Cr} = 0.1375 + 2.59 = 2.7275 \text{ kg}$$

In other words, it is estimated that the unit emits 2.7276 kg of Cr annually.

6.7 REFERENCES FOR SECTION 6

1. Overcash, M. J., and D. Pal. Design of Land Treatment Systems for Industrial Wastes--Theory and Practice. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. 1979. 684 pp.

2. Brown, K. W., G. B. Evans, and B. D. Frentrap. Hazardous Waste Land Treatment. Ann Arbor Press, Ann Arbor Michigan. 1983. 692 pp.

3. American Petroleum Institute. Land Treatment Practices in the Petroleum Industry. Washington, DC. June 1983.

4. American Petroleum Institute. The Land Treatability of Appendix VIII Constituents Present in Petroleum Industry Wastes. Document B-974-220, Washington, DC. May 1984.

5. GCA Corporation. Preliminary Model Plants for Treatment, Storage, and Disposal Facilities. Draft Technical Note, EPA Contract No. 68-01-6871, Assignment No. 13, prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

6. Englehart, P., and D. Wallace. Assessment of Hazardous Waste TSDF Particulate Emissions. Final Report. EPA Contract No. 68-02-3891, Assignments 5 and 13. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. October 1986.

7. Environmental Protection Agency. Compilation of Air Pollution Emission Factors (AP-42). Research Triangle Park, North Carolina. September 1988.

7.0 WASTE STABILIZATION

7.1 SOURCE DESCRIPTION

In this section the basic types of waste stabilization processes are discussed along with resulting PM_{10} emissions. Pozzolanic processes are emphasized based on a 1986 survey of TSDF facilities.

7.1.1 Site Characteristics

"Solidification" and "stabilization" both refer to treatment systems designed to accomplish one or more of the following: (a) improve handling and physical characteristics of the waste; (b) decrease the surface area across which transfer or loss of contained pollutants can occur; and/or (c) limit the solubility of, or to detoxify, any hazardous constituents contained in the wastes. Solidification implies that these results are obtained primarily (but not exclusively) via the production of a monolithic block of treated waste with high structural integrity. Stabilization techniques are beneficial because they limit the solubility or detoxify the waste contaminants, even though the physical characteristics of the waste may or may not be changed or improved. Stabilization usually involves addition of materials that ensure the hazardous constituents are maintained in their least soluble and/or toxic form.

The term "fixation," has fallen in and out of favor but is widely used in the waste treatment field as generally meaning any treatment system which solidifies and/or stabilizes the waste as described above. This is the restricted use of the term as contained in this document.

"Surface encapsulation" is a technique of waste treatment involving isolation of the waste material by placing a jacket or membrane of impermeable, chemically inert material between the waste and the environment. Ideally the jacket is bonded to the external surface of a solidified waste. Encapsulation of small particles is sometimes called "microencapsulation," but this term is used by processors to describe a wide array of different techniques and therefore has no specific meaning.

There are seven major categories of industrial waste stabilization systems:[1]

1. Cement-based processes.
2. Pozzolanic processes (not including cement).
3. Thermoplastic techniques (including bitumen, paraffin, and polyethylene incorporation).
4. Organic polymer techniques (including urea-formaldehyde, unsaturated polyester).
5. Surface encapsulation techniques (jacketing).
6. Self-cementing techniques (for high calcium sulfate sludges).
7. Glassification and production of synthetic minerals or ceramics.

Each will be described briefly below.

7.1.1.1 Cement-Based Processes. Five types of Portland cement are generally recognized, based on variations in their chemical composition and physical properties:[1]

1. Type I is the typical cement used in the building trade, and constitutes over 90% of the cement manufactured in the United States.
2. Type II is designed to be used in the presence of moderate sulfate concentrations (150 to 1,500 mg/kg) or where moderate heat of hydration is required.
3. Type III has a high early strength and is used where a rapid set is required.
4. Type IV develops a low heat of hydration and is usually prescribed for large-mass concrete work but has a long set time.
5. Type V is a special low-alumina, sulfate-resistant cement used with high sulfate concentrations (> 1,500 mg/kg).

The types that have been used for waste solidification are Type I and, to a smaller extent, Types II and V.

Most hazardous waste slurried in water can be mixed directly with cement, and the suspended solids will be incorporated into the rigid matrices of the hardened concrete. This process is especially effective for waste with high levels of toxic metals, since at the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates. Metal ions may also be incorporated into the crystal structure of the cement minerals that form. Materials in the waste such as sulfides, asbestos, latex, and solid plastic wastes may actually increase the strength and stability of the waste concrete.

7.1.1.2 Pozzolanic Processes (not containing cement). Waste fixation techniques based on lime products usually depend on the reaction of lime with a fine-grained siliceous (pozzolanic) material and water to produce a concrete-like solid (sometimes referred to as a pozzolanic concrete). The most common pozzolanic materials used in waste treatment are fly ash, ground blast-furnace slag, and cement-kiln dust. All of these materials are themselves waste products with little or no commercial value. The use of these waste products to consolidate another waste is often advantageous to the processor, who can treat two waste products at the same time. For example, the production of a pozzolanic reaction with power plant fly ash permits the flue gas cleaning sludge to be combined with the normal fly ash output and lime (along with other additives) to produce an easily-handled solid.

7.1.1.3 Thermoplastic Techniques (including bitumen, paraffin, and polyethylene). The use of thermoplastic solidification systems in radioactive waste disposal has led to the development of waste containment systems that can be adapted to industrial waste. In processing radioactive waste with bitumen or other thermoplastic material, the waste is dried, heated, and dispersed through a heated plastic matrix. The mixture is then cooled to solidify the mass, and it is usually buried in a secondary containment system such as a steel drum. Variations of this treatment system can use thermoplastic organic materials such as paraffin or polyethylene.

The above process requires some specialized equipment to heat and mix the waste and plastic matrices, but equipment for mixing and extruding waste plastic is available. The ratio of matrix to waste is generally quite high--a 1:1 to 1:2 ratio of incorporation material to waste (on a dry-weight basis).[1] The plastic in the dry waste must be mixed at temperatures ranging from 130°C to 230°C, depending on the melting characteristics of the material and type of equipment used.[1]

7.1.1.4 Organic Polymer Processes. Organic polymer techniques were developed as a response to the requirement for solidification of waste for transportation. The most thoroughly tested organic polymer solidification technique is the urea-formaldehyde (UF) system. The polymer is generally formed in a batch process where the wet or dry wastes are blended with a prepolymer in a waste receptacle (steel drum) or in a specially-designed mixer. When these two components are thoroughly mixed, a catalyst is added, and mixing is continued until the catalyst is thoroughly dispersed. Mixing is terminated before the polymer has formed and the resin-waste mixture is transferred to a waste container, if necessary. The polymerized material does not chemically combine with the waste--it forms a spongy mass that traps the solid particles. Any liquid associated with the waste will remain after polymerization. The polymer mass must often be dried before disposal.

7.1.1.5 Surface Encapsulation Techniques (jacketing). Many waste treatment systems depend on binding particles of waste material together. To the extent to which the binder coats the waste particles, the wastes are encapsulated. However, the systems addressed under surface encapsulation are those in which a waste that has been pressed or bonded together is enclosed in a coating or jacket of inert material. A number of systems for coating solidified industrial wastes have been examined.

7.1.1.6 Self-Cementing Processes. Some industrial wastes such as flue-gas cleaning or desulfurization sludges contain large amounts of calcium sulfate and calcium sulfite. At least one technology has been developed to treat these types of wastes so that they become self-cementing. Usually a small portion (8% to 10% by weight) of the dewatered waste sulfate/sulfite sludge is calcined under carefully controlled conditions to produce a partially dehydrated cementitious calcium sulfate or sulfite. This calcined waste is then reintroduced into the bulk of the waste sludge along with other proprietary additives. Fly ash is often added to adjust the moisture content. The finished product is a hard, plaster-like material with good handling characteristics and low permeability.

7.1.1.7 Glassification and Production of Synthetic Minerals or Ceramics. Where material is extremely dangerous or radioactive, it is possible to combine the waste with silica and either fuse the mixture in glass or to form a synthetic silicate mineral. Glasses or crystalline silicates are only very slowly leached by naturally occurring waters, so these waste products are generally considered to be safe materials for disposal without secondary containment. There are no known applications of glassification processes currently in operation.[1]

Of those described above, pozzolanic processes will be emphasized in the following sections. Other stabilization processes should be evaluated on a site-specific basis using the basic information contained in Cowherd et al.[2]

7.1.2 Emission Sources

The exact sources and character of the particulate emissions generated by waste stabilization operations depend on the type of process and disposal method used. However, in general, pozzolanic waste stabilization processes involve the following basic sequence of operations: (a) initial load-out of the liquid material into a mix bin; (b) addition of solid material to the bin; (c) mixing of liquid and solid material; and (d) removal of the mixture (i.e., stabilized waste) from the bin.[3] At some sites, after mixing, the material is transferred from the bin to off-highway trucks by an excavator. The off-highway trucks then transport the material to the landfill. At other sites, material is transferred directly from the bin to temporary storage piles adjacent to an active landfill surface. Landfill equipment then spreads the material over the landfill surface. A general flow diagram of pozzolanic stabilization processes is shown in Figure 7-1.

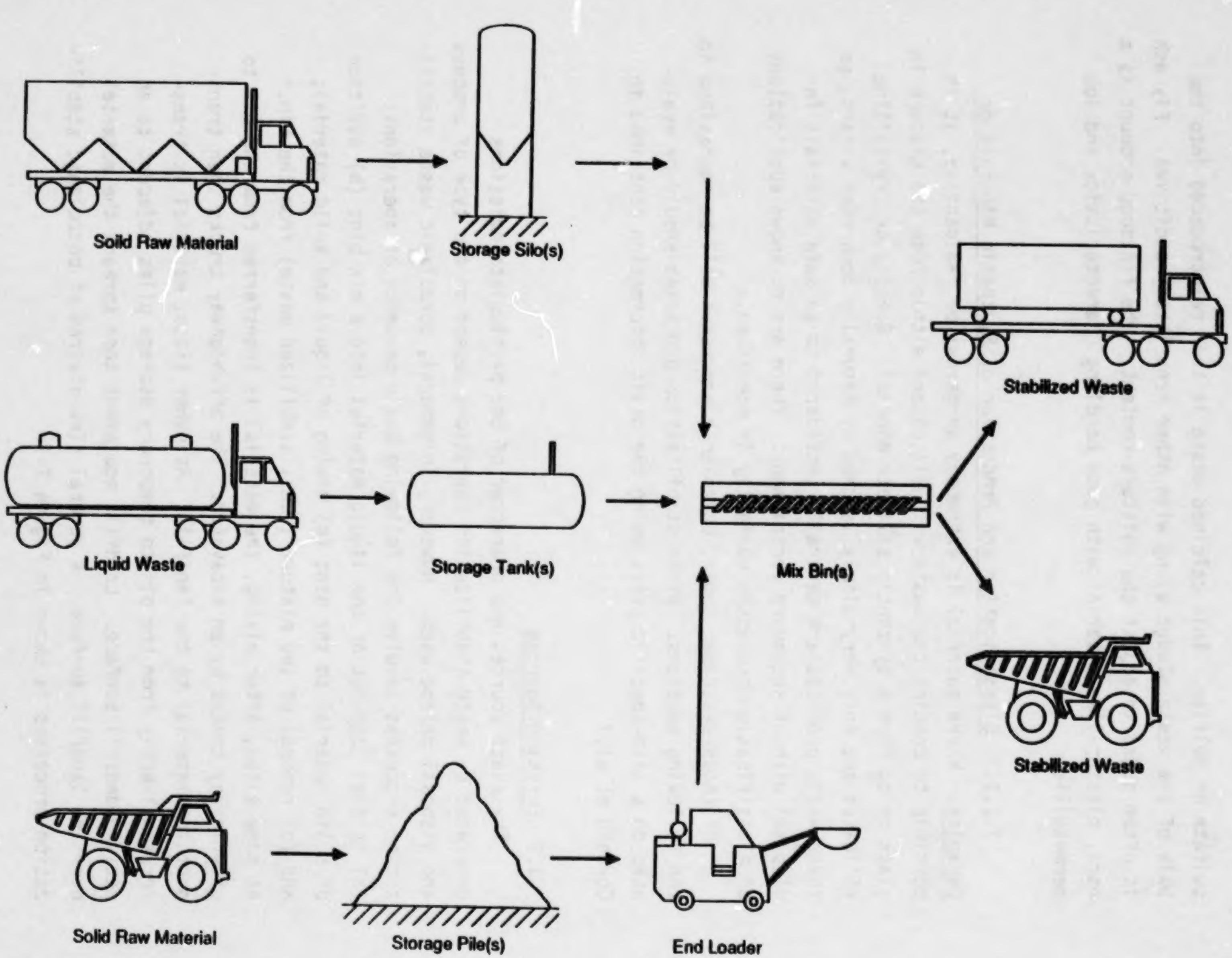

Solid Raw Material
Storage Silo(s)
Liquid Waste
Storage Tank(s)
Mix Bin(s)
Stabilized Waste
Stabilized Waste
Solid Raw Material
Storage Pile(s)
End Loader

Figure 7-1. General pozzolanic process flow diagram.

In the above process flow, fugitive PM_{10} can be generated during the transfer and handling of solid materials prior to being mixed with the liquid waste, during transfer and handling of the stabilized waste, and from truck and loader traffic operating near the process equipment. The surface over which the vehicles operate may either be paved or unpaved as the case may be.

The extent of the fugitive emissions generated from stabilization processes depend to a major extent on whether the actual mixing of liquid and solid materials occur within a building or enclosure. If the process is completely enclosed, occupational exposure would be of greater concern than that of emissions to the atmosphere. However, spillage of stabilized waste from vehicles onto travel surfaces can be of concern regardless of whether the process is enclosed or completely or partially exposed to the atmosphere.

7.2 ESTIMATION OF UNCONTROLLED EMISSIONS

The estimation of uncontrolled emissions from waste stabilization processes involves both the determination of PM_{10} emission rates from the dust-generating source(s) and their associated level(s) of contamination. Both topics are discussed below.

7.2.1 Particulate Emission Rates

Estimation of uncontrolled particulate emissions from waste stabilization follows the general model (Eq. 1-2) presented in Section 1. For convenience, it is reiterated below with terms potentially applicable to stabilization units:

$$R_i = \sum_{j=1}^{n} \alpha_{ij} \cdot e_{ij} \cdot A_{ij} \qquad (7\text{-}1)$$

where R_i = emission rate of contaminated airborne particulate (kg/yr) for a given stabilization process, consisting of n identifiable unit operations

α_{ij} = fraction of contamination in particulate emissions for the jth stabilization operation (μg/g)

e_{ij} = emission factor(s) (mass/source extent)
A_{ij} = source extent(s) (source dependent units)

For waste stabilization, the n unit operations correspond to those outlined in Section 7.1--transfer and handling of solid raw materials; transfer and handling of stabilized waste; and vehicle traffic. Wind erosion emissions are considered to be negligible in the vicinity of waste stabilization processes.

Subject to the limitations/uncertainties discussed in Section 1, Table 7-1 provides an emission factor (E_{ij}) for each of the unit operations that may occur at or near a waste stabilization process. Except for the α_{ij} term, there are certain aspects of each emission factor that should be noted prior to estimation of PM_{10} emissions for a given source. These aspects are discussed below.

For the transfer and handling of solid raw materials, the materials used to mix with the waste (e.g., fly ash, cement kiln dust, etc.), generally consist of fine particles which fall outside of the range of silt values for the load-in/load-out emission factor equation published in Section 11.2.3 of AP-42.[4] Therefore, it is recommended that the PM_{10} emission factor developed by Muleski et al. for the loading of fly ash into open trucks be used instead.[5] Although this emission factor is not currently published in AP-42, it would be expected that the nature of the material and dust-generating process more closely represent those used in waste stabilization.

For the transfer of stabilized waste either into haul trucks or into temporary storage, the load-in/load-out emission factor equation published in Section 11.2.3 of AP-42 can be used.[4] Since this factor was originally developed for dry aggregate materials, it should only be used with caution. An "A" quality rating is applicable to materials with silt contents between 0.44 and 19% and moisture contents of 0.25 to 4.8%. If the characteristics of the stabilized waste do not conform to these ranges, the quality rating is reduced by one level. It is recommended, therefore, that waste-specific data be used in lieu of the "default" parameters listed in Table 7-1.

TABLE 7-1. PM-10 EMISSION FACTORS AND CORRECTION PARAMETERS FOR WASTE STABILIZATION[a]

Unit operation	PM-10 Emission factor		Source of PM-10 emission factor	Range of correction parameters applicable to emission factor	Correction parameters measured in recent survey[b]
Unpaved travel surfaces	$E = 0.612 \cdot \frac{s}{12} \cdot \frac{S}{48} \cdot \left(\frac{W}{2.7}\right)^{0.7} \cdot \left(\frac{w}{4}\right)^{0.5} \cdot \frac{365-p}{365}$ = kg/VKT	(7-2)	AP-42, Sec. 11.2.1	s = 4.3%-20% S = 21-64 km/h W = 2.7-142 Mg w = 4-13	s = 17.8% M = 16.6%
Paved travel surfaces	$E = 0.22\ (sL/12)^{0.3}$ kg/VKT	(7-3)	AP-42, Sec. 11.2.6	sL = 2-240 gm/m^2 W = 6-42 Mg	N/A
Raw material transfer and handling	E = 0.00085 kg/Mg		Muleski et al., 1986[c]	s = 25%-40%[d] M = 26%-30%	N/A
Stabilized waste transfer and handling	$E = 0.00056\ \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$ kg/Mg	(7-4)	AP-42, Sec. 11.2.3	s = 0.44%-19% U = 0.6-6.7 m/s M = 0.25%-4.8%	s = 1.6% M = 28%

[a] s = silt content (wt. %); S = mean vehicle speed (km/h); W = mean vehicle weight (Mg); w = mean number of vehicle wheels (dimensionless); p = d/yr > 0.01 in precipitation (Figure 7-2); sL = silt loading (g/m^2); M = material moisture content (wt. %); and U = mean wind speed (m/s).

[b] Source: Englehart, P. E., et al., "Assessment of Hazardous Waste TSDF Particulate Emissions," Final Report, EPA Contract No. 68-02-3891, Work Assignments 5 and 13, U.S. Environmental Protection Agency, OAQPS, Research Triangle Park, NC, October 1986. NA = not available. May be used as "default" values if no site-specific data are available.

[c] Source: Muleski, G. E., et al., "Measurement of Fugitive Emissions in a Coal-Fired Power Plant," Proceedings: Sixth Symposium on Transfer and Utilization of Particulate Control Technology, Vol. 3, November 1986.

[d] Determined by dry sieving. These values are probably low based on typical material characteristics published in the literature.

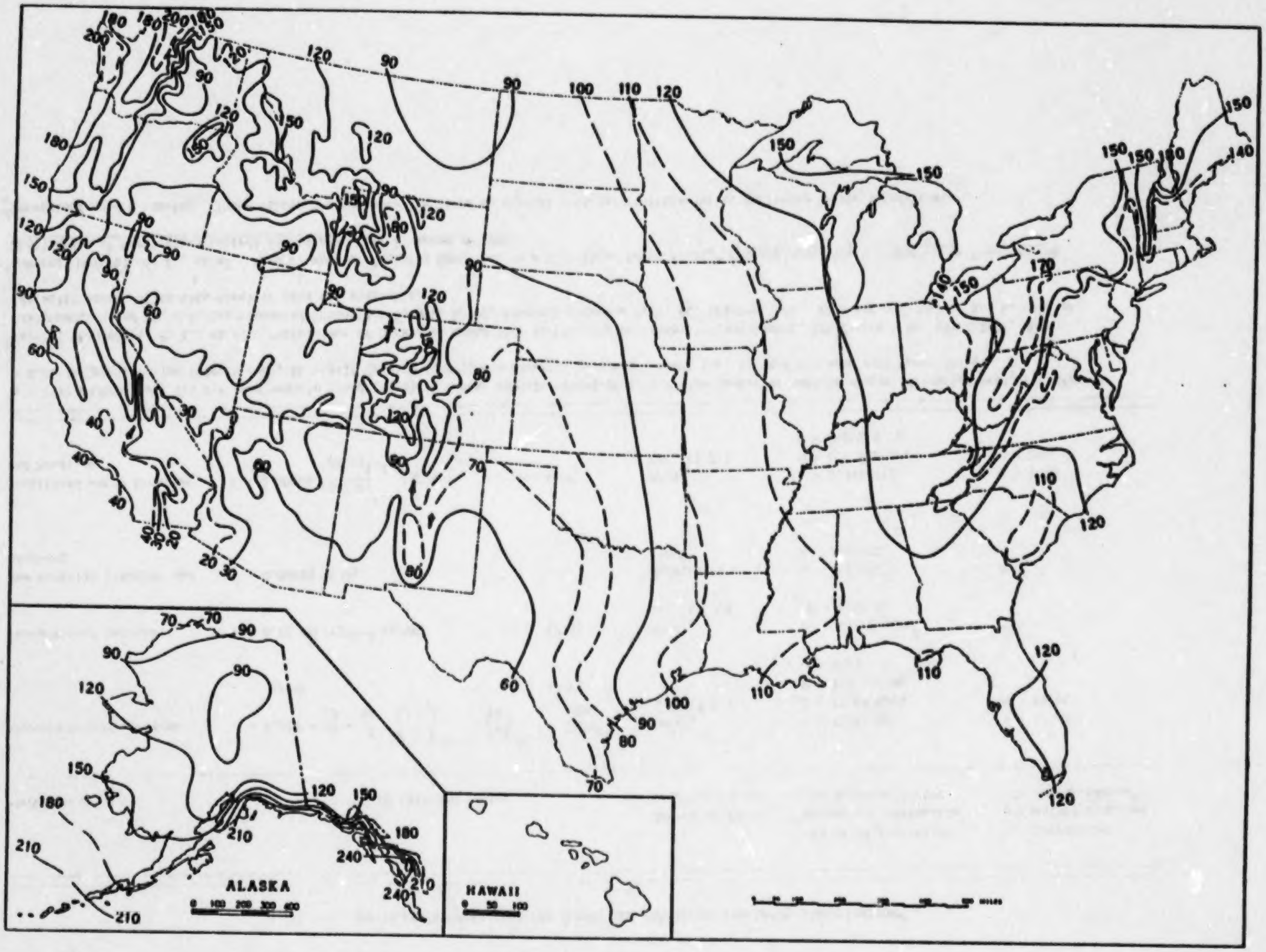

ALASKA
HAWAII
0 100 200 300 400
0 50 100
90
100
110
120
150
140
180
200
60
70
80
40
30
20
210
240
MILES

Figure 7-2. Mean annual number of days with at least 0.01 in of precipitation. As noted in Reference 2, patterns are too complex in Hawaii for inclusion on map. (Means for Hilo, Honolulu, and Lihue are 148, 204, and 90 days per year, respectively.)

Finally, for vehicle traffic operating near the stabilization process, the activities are considered to be similar to those tested during the development of the paved and unpaved road equations published in Sections 11.2.1 and 11.2.6 of AP-42.[4] It should be noted, however, that unlike generic roads, the emissions from vehicle traffic near stabilization processes can be contaminated with organic compounds and/or RCRA metals.

Also included in Table 7-1 are material "correction parameters" for each of the above emission factors. One column in the table provides those material characteristics used in the derivation of the PM_{10} emission factor, and the second (and final) column presents available data from a recent survey of TSDFs.[3] These final values can be used as default parameters in lieu of source-specific data, if necessary. Please note, however, that the default values provided in Table 7-1 are based on very limited measurements and thus should not be considered indicative of the industry as a whole.

7.2.2 Level of Contamination (α)

For waste stabilization processes, α depends to a major extent on the types of liquid waste being treated and the type of process being used (Section 7.1.1). Because of the great variability from site to site, it is recommended that site-specific sampling and analysis be performed to characterize contamination levels of the source material. The following discusses potential contamination as related to the major dust-emitting sources found in stabilization processes. Results of a recent survey are also provided to supply some indication as to the contamination found in the two stabilization processes surveyed.

With regard to potential contaminated emissions created during the transfer and handling of solid raw materials (prior to being added to the waste), it would be expected that the PM_{10} emissions would contain only those compounds inherent in the solid bulk material. As these materials are generally not considered to be hazardous, it would be expected that the resulting fugitive emissions should not be contaminated to any significant extent. This is not the case, however, during handling and transfer of the stabilized waste prior to disposal and for vehicular traffic operating in the vicinity of the process.

Fugitive PM_{10} generated during the handling of stabilized waste can be contaminated with various organic compounds and/or RCRA metals. For example, during a limited survey of two TSDFs, an average total concentration of RCRA metals and semivolatile organic compounds in the samples collected was found to be 919 and 103 µg/g, respectively.[3] These concentrations represent average values obtained from one sample taken in the vicinity of the process equipment at one facility and one sample of stabilized waste collected at a second site.

Contaminated emissions can also be generated by truck and loader traffic operating in the vicinity of the stabilization process. Contamination of paved and unpaved surfaces can result from spillage during handling and transport of the stabilized waste which is subsequently reentrained as fugitive dust. Contamination can also result from migration of contaminated material from other on-site treatment areas which is transferred to and from plant roads, etc. This has been discussed previously in Section 2.2.3 of this manual.

Finally, Table 7-2 provides data for RCRA metals determined in a survey conducted in 1986.[3] Again, it should be cautioned that the values presented in Table 7-2 are based on limited sampling and thus should not be considered indicative of the industry as a whole. Also note that the data are for silt fractions only since this parameter is used in most AP-42 emission factor equations for fugitive sources.[4]

7.3 CONTROL TECHNIQUES

While there has been no actual field testing of particulate control techniques at HW TSDFs, it is reasonable to assume that much of the experience and information developed in more traditional industries (e.g., iron and steel) can be applied. In practice, however, complications may arise because of competing (and potentially contradictory) objectives in controlling overall particulate emissions vs. contaminated fractions thereof.

TABLE 7-2. SUMMARY OF RCRA METALS CONCENTRATION FOR WASTE STABILIZATION SAMPLES[a]

RCRA Metal	Concentration in sample (μg/g)[b]	
	Unpaved surface	Stabilized waste
Arsenic (As)	11.3	14.8
Barium (Ba)	191	202
Cadmium (Cd)	2.1	18.8
Chromium (Cr)	67.4	337
Lead (Pb)	114	866
Mercury (Hg)	0.8	0.11
Selenium (Se)	< 1	1.7
Silver (Hg)	< 10	11.5

[a] From Reference 3.

[b] Concentration of specific RCRA metal in silt (≤ 74 μm physical diameter) fraction. < indicates below detection limit.

7.3.1 Preventive Controls

Preventive controls, as applied to waste stabilization, consists of two basic approaches: work practice controls, and reduction in source extent. Work practice controls include those measures which reduce emissions potential either through a modification of the process or its operation. Reduction in source extent implies some decrease in the level of process operation which lowers either gross or contaminated PM_{10} emissions to the atmosphere.

The type of preventive controls used at a specific facility depend to a large extent on the individual process and its operation with respect to other activities occurring on-site. The following are possible preventive measures to reduce fugitive dust emissions from waste stabilization processes:

7.3.1.1 Transfer and Handling of Solid Raw Materials.

- Work practice controls: The principal method would be to use elevated hoppers or silos to store and dispense solid stabilization materials to reduce emissions potential during load-in/load-out and to eliminate loader travel to and from the process area. Finely divided materials should be pneumatically or mechanically conveyed to fill hoppers or silos instead of using some type of wheeled or tracked loader.

- Source extent reduction: Restrict vehicle traffic in process area using work practice controls indicated above.
- Comments: Although the emission factor for raw materials handling and transfer (Table 7-1) is not directly related to the particle size of the material, finely divided stabilizers would tend to have a higher emissions potential than coarser products. It is recommended that coarse raw materials be used whenever possible.

7.3.1.2 Transfer and Handling of Stabilized Waste.

- Work practice controls: The use of containers (e.g., roll-offs) for the transfer of stabilized waste to haul trucks or for temporary storage near the process area is recommended. Enclosure of mix trough or bins is also suggested to reduce entrainment of finely divided materials during mixing of solids and liquid waste.
- Source extent reduction: Reduce number of transfer operations which stabilized waste must undergo prior to disposal.
- Comments: Elimination of temporary open storage of stabilized waste would be expected to reduce handling emissions as well as control the transfer of contamination to travel surfaces and migration to other parts of the facility. Containerization would also eliminate the use of wheeled or tracked loaders with their associated travel across potentially contaminated paved and/or unpaved surfaces (see below).

7.3.1.3 Vehicle Travel in Process Area.

- Work practice controls: The main preventive technique is to pave unpaved surfaces in the general vicinity of the process for delivery of raw materials and removal of stabilized waste. For paved surfaces, any method to reduce spillage and improve general housekeeping to minimize silt loadings is recommended. Speed limitations for all vehicles can also reduce emissions.

- Source extent reduction: Eliminate the use of loaders by automation of the process operation. Reduction or elimination of unnecessary traffic in process area is also suggested.
- Comments: If loaders are used, this equipment should be "dedicated" to the stabilization process and not used for other operations within the facility. By restricting the use of equipment to one operation, the spread of contamination is limited.

It should be noted that the measures listed above are by no means all-inclusive but are intended to provide guidance as to the general types of practices which could be used to reduce emissions from stabilization processes. Also, the techniques listed are based on a limited survey of stabilization processes performed prior to the issuance of RCRA Part B permits for TSDFs.[3] It would be expected, therefore, that a number of the preventive techniques described above may have already been implemented in currently operating systems.

7.3.2 Mitigative Controls

In addition to preventive measures, certain mitigative controls can also be applied to reduce emissions from waste stabilization processes. As was stated previously, these measures are essentially identical to those applied at other industrial facilities to control gross PM_{10}. Caution should be exercised, however, to apply the control in an appropriate manner such as not to exacerbate any potential for further contamination of source material (and the resulting PM_{10} emissions). The following describes mitigative control techniques applicable to waste stabilization.

For transfer and handling of solid raw materials, a number of control options are available depending on how the waste is processed. If open storage is used, the only viable alternative is the use of wind screens or barriers to provide a sheltered area for transfer and handling of the solid materials.[6] Either portable screens, permanent barriers, or some type of partial enclosure (e.g., three-sided bunker) could be used for this purpose depending on site conditions. It should also be noted that wet suppression is also available to control fugitive PM_{10} from raw materials handling but this technique may not be compatible with either the liquid waste or the stabilization process being used and thus is not generally recommended.

If a silo or hopper is used to store and dispense solid raw materials, a traditional capture/collection system could be used to control the PM_{10} generated.[6] As the name implies, capture/collection systems consist of some form of hood or other ventilated device to capture the dust emissions from the source with the suspended particles being removed from the air stream using some type of dust collector (e.g., fabric filter). These systems are reasonably expensive, but, if properly designed and maintained, are also very effective in reducing dust emissions. Additional information on the design and operation of capture/collection systems can be found in Cowherd and Kinsey.[6]

With regard to the transfer and handling of the stabilized waste, the number of control alternatives is limited. In general, the waste is relatively moist with little dust emission potential as it is initially generated by the process. The greatest dusting potential is present when the waste begins to dry prior to disposal. If temporary storage piles are used, wet suppression using water or water plus a surfactant could be employed to control dust emissions. A similar system could also be utilized during the loading of waste into haul trucks, if required. The major emissions potential during transfer and handling of stabilized waste really comes from vehicle traffic in the process area as discussed below.

In most cases, vehicle travel on paved and unpaved travel surfaces is the major source of fugitive PM_{10} at TSDFs. Spillage of waste material onto these surfaces contaminates the surface with RCRA metals or organic compounds which results in the generation of contaminated PM_{10}.

Available controls for unpaved travel surfaces include speed and traffic reduction, paving, graveling, watering, and chemical stabilization. However, in many cases, the only practical technique to control dust generation from unpaved travel surfaces is the use of watering. The use of chemical dust suppressants at hazardous waste TSDFs is also possible but, in general, not practical in most applications because of water quality considerations. Care must be exercised in the use of water for dust control in that it too has the potential to spread contamination and cause potential problems with regard to surface and groundwater.

With regard to vehicle travel over paved surfaces, some type of surface cleaning is required to reduce silt loadings and thus dust emissions. Either vacuum sweeping, flushing, or a combination of broom sweeping and flushing can be used to clean paved surfaces. MRI has found that the most effective technique seems to be water flushing followed by broom sweeping.[2,6] Again, care must be exercised when flushing paved surfaces so as not to spread contamination from the process area to other parts of the facility. Therefore, a site-specific evaluation should be performed to determine the most applicable method for reducing silt loadings on paved surfaces.

7.4 CONTROL PERFORMANCE ESTIMATION

The following sections provide available techniques to estimate the performance of the dust control methods discussed above and their associated cost elements. Additional data on these methods can be found in Cowherd and Kinsey and Cowherd et al.[2,6]

7.4.1 Wind Fences or Barriers

Wind fences and screens are applicable to a wide variety of fugitive dust sources. They can be used to control wind erosion emissions from raw material storage piles as well as to provide a sheltered area for materials handling operations to reduce entrainment during load-in/load-out, etc. Fences and screens can be portable and thus capable of being moved around the site, as needed.

The control efficiency of wind fences is dependent on the physical dimensions of the fence relative to the source being controlled. In general, a porosity (i.e., percent open area) of 50% seems to be optimum for most applications. (Note that no data directly applicable to waste stabilization activities were found.) According to a recent field study of small soil storage piles, a screen length of five times the pile diameter, a screen-to-pile distance of twice the pile height, and a screen height equal to the pile height was found best.[2]

A 1988 laboratory wind tunnel study of windbreak effectiveness for coal storage piles showed area-averaged wind speed reductions of ~ 50% to 70% for a 50% porosity windbreak with height equal to the pile height and length equal to the pile base.[7] The windbreak was located three pile heights upwind from the base of the pile. Based on the 1.3 power given in Table 7-1, speed reductions of ~ 50% to 70% would correspond to ~ 60% to 80% control of material handling PM_{10} emissions.

One of the real advantages of wind fences for the control of fugitive PM_{10} involves the low capital and operating costs. These involve the following basic elements:

- Capital equipment
  - Fence material and supports
  - Mounting hardware
- Operating and maintenance expenditures
  - Replacement fence material and hardware
  - Maintenance labor

The following cost estimates (in 1980 dollars) were developed for wind screens applied to aggregate storage piles:[2,7]

- Artificial wind guards
  - Initial capital cost = \$12,000 to \$61,000
- Vegetative wind breaks
  - Initial capital cost = \$45 to \$425/tree

Because of the lack of quantitative data on costs associated with wind screens, it is recommended that local vendors be contacted to obtain more detailed data for capital and operating expenses. Also, since wind fences and screens are relatively "low tech" controls, it may be possible for the site personnel to construct the necessary equipment with less expense.

7.4.2 Capture/Collection Systems

Many industrial fugitive emissions have traditionally been controlled by capture/collection, or industrial ventilation systems. These systems have three primary components: (a) a hood or enclosure to capture emissions that escape from the process; (b) a dust collector that separates entrained particulate from the captured gas stream; and (c) a ducting or ventilation system to transport the gas stream from the hood or enclosure to the air pollution control device. Capture devices (or hoods) generally can be classified as one of three types: enclosure; capture hood; or receiving hood. These are described elsewhere.[6]

The selection of a suitable capture device is source-specific and depends on both operating and emissions characteristics. Factors influencing selection include location of the source with respect to other operations, degree of process movement (if any), space needed for worker or equipment access to the process, physical size of the operation or process, and momentum of the particulate plume due to buoyancy or inertia applied by the process.

The two primary parameters involved in the design of effective local exhaust or hooding systems are: (a) locating the hood (defined in the broad sense described above) to contain emitted particulate as much as possible, and (b) providing adequate flow to capture any particulate not contained by the hood and prevent the escape of all particulate from the hood. The goal of hood design is to install a hood or enclosure that provides effective particulate control at the minimum exhaust volume.

In the case of raw materials handling in waste stabilization processes, some form of local capture hood or enclosure would generally be used to control fugitive PM_{10} emissions where hoppers or silos are employed. Airflow exhausted from a local capture hood installed on an operation involving material movement serves two purposes: the exhaust must overcome induced airflow created by material motion; and the exhaust must provide sufficient velocity to capture particulate which escapes the confines of the hood. The predominant function is dependent on hood type. If an enclosure is used, control of induced airstreams is the primary objective. If the operation requires an exterior hood, particulate capture is the primary airflow function.

For those systems which can be controlled by complete or partial enclosure, the airflow at the hood should be sufficient to overcome induced air currents inherent to the process and to provide an inward air velocity through all openings of about 50 to 200 ft/min.[6] The volumes needed to overcome induced air currents associated with specific processes are discussed below. The flow needed to provide adequate velocities at openings can be calculated by the formula:[6]

$$Q = A\ V \tag{7-5}$$

where Q = required airflow (ft^3/min)
A = cross-sectional area of openings (ft^2)
V = required velocity at openings (ft/min)

Material transport creates an induced airflow which must be overcome to effectively control fugitive emissions. The following equation is used for calculating induced airflow at transfer points:[6]

$$Q = 10.0\ A_u \sqrt[3]{\frac{RS^2}{D}} \tag{7-6}$$

where Q = induced airflow (ft^3/min)
A_u = feed opening (ft^2)
R = rate of material flow (tons/h)
S = height of fall (ft)
D = average particle diameter (ft)

The objective of a capture hood is to provide a capture velocity of 50 to 75 ft/min at the farthest capture point from the hood. The total flow required to achieve this velocity is:[6]

$$Q = V\ (10\ X^2 + A) \tag{7-7}$$

where Q = required airflow (ft^3/min)
V = required capture velocity (ft/min)

X = distance from hood to farthest null point (ft)
A = cross-sectional area of hood (ft^2)

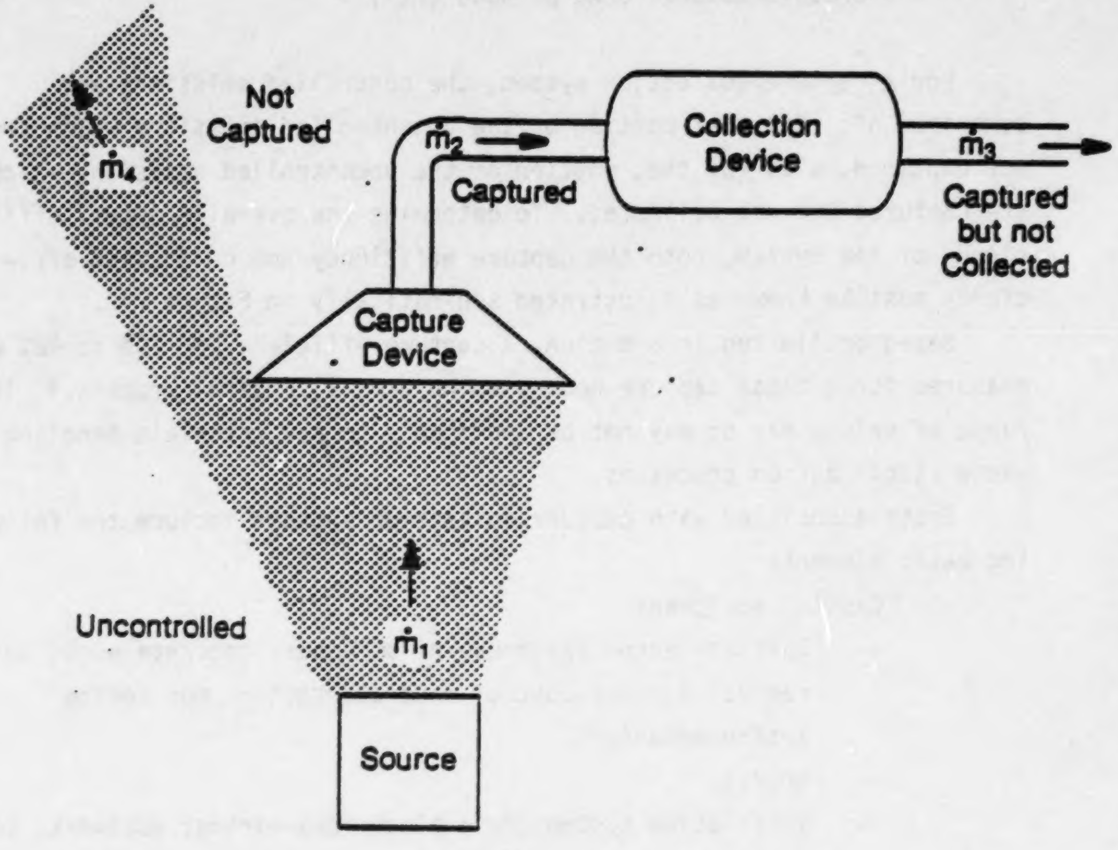
For a capture/collection system, the controlled emissions are comprised of: (a) that portion of the uncontrolled emissions which are not captured, plus (b) that portion of the uncontrolled emissions which are captured but not collected. To determine the overall control efficiency of the system, both the capture efficiency and collection efficiency must be known as illustrated schematically in Figure 7-3.

Based on limited information, a capture efficiency of 70% to 98% was measured for a close capture hood used on a metallurgical process.[6] This range of values may or may not be applicable to raw materials handling in waste stabilization processes.

Costs associated with capture/collection systems include the following basic elements:

- Capital equipment
  -- Dust collector (baghouse or scrubber; concrete work; dust removal system; control instrumentation; monitoring instrumentation)
  -- Hood(s)
  -- Ventilation system (fan; electrical wiring; ductwork; concrete support work; damper system; expansion joints)
  -- Dust storage system
- Operating and maintenance expenditures
  -- Utilities (electricity; water)
  -- Supplies (replacement bags; fan motors; chemical additives for scrubber)
  -- Labor (system operation; control device maintenance and cleaning; ductwork maintenance)
  -- Disposal of collected particulate

Reference 8 estimates the following costs (1980 dollars) for a pneumatic conveying system vented to a fabric filter (this also includes a ventilated enclosure for unloading): capital = $130,000 and operating = $33,000/yr.


Not Captured
$\dot{m}_4$
$\dot{m}_2$
Captured
Collection Device
$\dot{m}_3$
Captured but not Collected
Capture Device
Uncontrolled
$\dot{m}_1$
Source

$$\text{Control Efficiency (\%)} = \frac{\dot{m}_1 - (\dot{m}_3 + \dot{m}_4)}{\dot{m}_1} \times 100$$

where $\dot{m}_1 = \dot{m}_2 + \dot{m}_4$

Figure 7-3. Performance evaluation of capture/collection systems.

7.4.3 Wet Suppression

Wet suppression of stabilized waste handling operations is similar to that used for storage piles. However, in addition to plain water this technique can also use water plus a chemical surfactant or micronized foam to control gross PM_{10}.

Surfactants added to the water supply allow particles to more easily penetrate the water droplet and increase the total number of droplets, thus increasing total surface area and contact potential. Foam is generated by adding a chemical (i.e., detergent-like substance) to a relatively small quantity of water which is then vigorously mixed to produce small bubble, high energy foam in the 100 to 200-μm size range. The foam uses very little liquid volume, and when applied to the surface of the bulk material, wets the fines more effectively than untreated water.

The control efficiency of wet suppression for materials storage and handling is dependent on the basic application parameters which include: the amount of water, water plus surfactant, or foam applied per unit mass or surface area of material handled (i.e., liters per metric ton or square meter); if not continuous, the time between reapplications; the amount of surfactant added to the water (i.e., dilution ratio), if any; the method of application including the number and types of spray nozzles used; and applicable meteorological conditions occurring on-site.

The only viable approach to estimating the control efficiency of wet suppression in stabilization processes involves the use of the recently developed materials handling equation published in AP-42.[4] This equation was presented previously in Table 7-1. By determining the "uncontrolled" moisture content of the material and again after wet suppression, the control efficiency can be determined by:

$$CE = 100(e_u - e_c)/e_u \qquad (7\text{-}8)$$

where CE = PM_{10} control efficiency in percent

e_u = "uncontrolled" PM_{10} emission factor

e_c = "controlled" PM_{10} emission factor

The above calculations would necessitate the determination of the amount of water added to the material by laboratory analysis. This could be accomplished by taking grab samples of the material before and after application of the wet suppression technique being employed. Sampling and analysis techniques are described in Appendix D.

Costs associated with wet suppression systems include the following basic elements:

- Capital equipment
  - Spray nozzles or other distribution equipment
  - Supply pumps and plumbing (plus weatherization)
  - Water filters and flow control equipment
  - Tanker truck (if used)
- Operating and maintenance expenditures
  - Water and chemicals
  - Replacement parts for nozzles, truck, etc.
  - Operating labor
  - Maintenance labor

Reference 2 estimates an initial capital cost of a stationary wet suppression system using plain water to be $18,400 per system (1985 dollars). The costs associated with a wet suppression system using chemical surfactants for the unloading of limestone from trucks at aggregate processing plants (in 1980 dollars) have been estimated at: capital = $72,000; annual = $26,000. These costs are based on a stationary system and may not be indicative of those used at waste stabilization sites.

7.4.4 Watering of Unpaved Surfaces

Watering of unpaved surfaces prevents (or suppresses) the release of fine particulate from the surface through the action of mechanical disturbance or wind. The water acts to bind the smaller particles to the larger material thus reducing emissions potential.

The control efficiency of watering of unpaved surfaces is a direct function of the amount of water applied per unit surface area (liters per square meter), the frequency of application (time between reapplication), the volume of traffic traveling over the surface between applications, and prevailing meteorological conditions (e.g., wind speed, temperature, etc.). A number of studies have been conducted with regard to the efficiency of watering to control dust, but few have quantified all parameters listed above. Additional details can also be found in Sections 2.2.3.2 and 2.2.4.3 of this document.

For compacted unpaved surfaces found near waste stabilization processes, an empirical model for the performance of watering as a control technique has been developed. The model is:

$$C = 100 - \frac{0.8\ p\ d\ t}{i} \qquad (7\text{-}9)$$

where C = average control efficiency (%)
p = potential average hourly daytime evaporation rate (mm/h)
d = average hourly daytime traffic rate (vehicles/h)
i = application intensity (L/m^2)
t = time between applications (h)

The term p in the above equation is determined using Figure 7-4 and the relationship:

$$p = \begin{cases} 0.0049\ E\ \text{(annual average)} & (7\text{-}10a) \\ 0.0065\ E\ \text{(worst case)} & (7\text{-}10b) \end{cases}$$

where p = potential average hourly daytime evaporation rate (mm/h)
E = mean annual pan evaporation (inches) from Figure 7-4

Note that Figure 7-4 does not present data for Alaska and Hawaii. Readers responsible for those portions of the country should consult local meteorological data from local weather stations, state universities, etc., for input to Eqs. 7-10a and 7-10b.

An alternative approach (which is potentially suitable for a regulatory format) is shown as Figure 7-5. Figure 7-5 shows that, between the average uncontrolled moisture content and a value of twice that, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content.

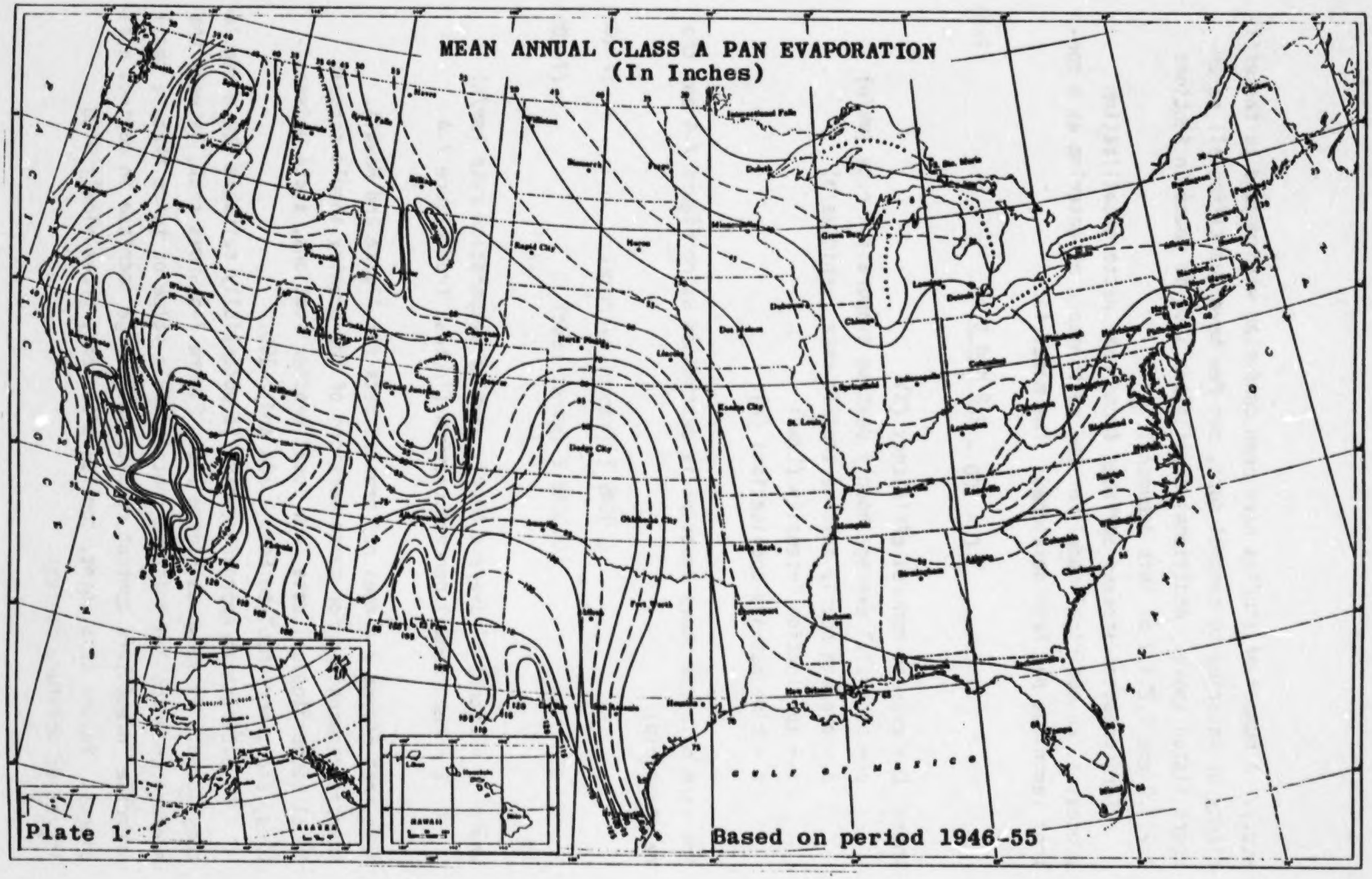

MEAN ANNUAL CLASS A PAN EVAPORATION
(In Inches)
PACIFIC OCEAN
GULF OF MEXICO
HAWAII
ALASKA
Plate 1
Based on period 1946-55

Figure 7-4. Annual evaporation data for the contiguous United States (as diagrammed in the "Climatic Atlas of the United States," June 1968).

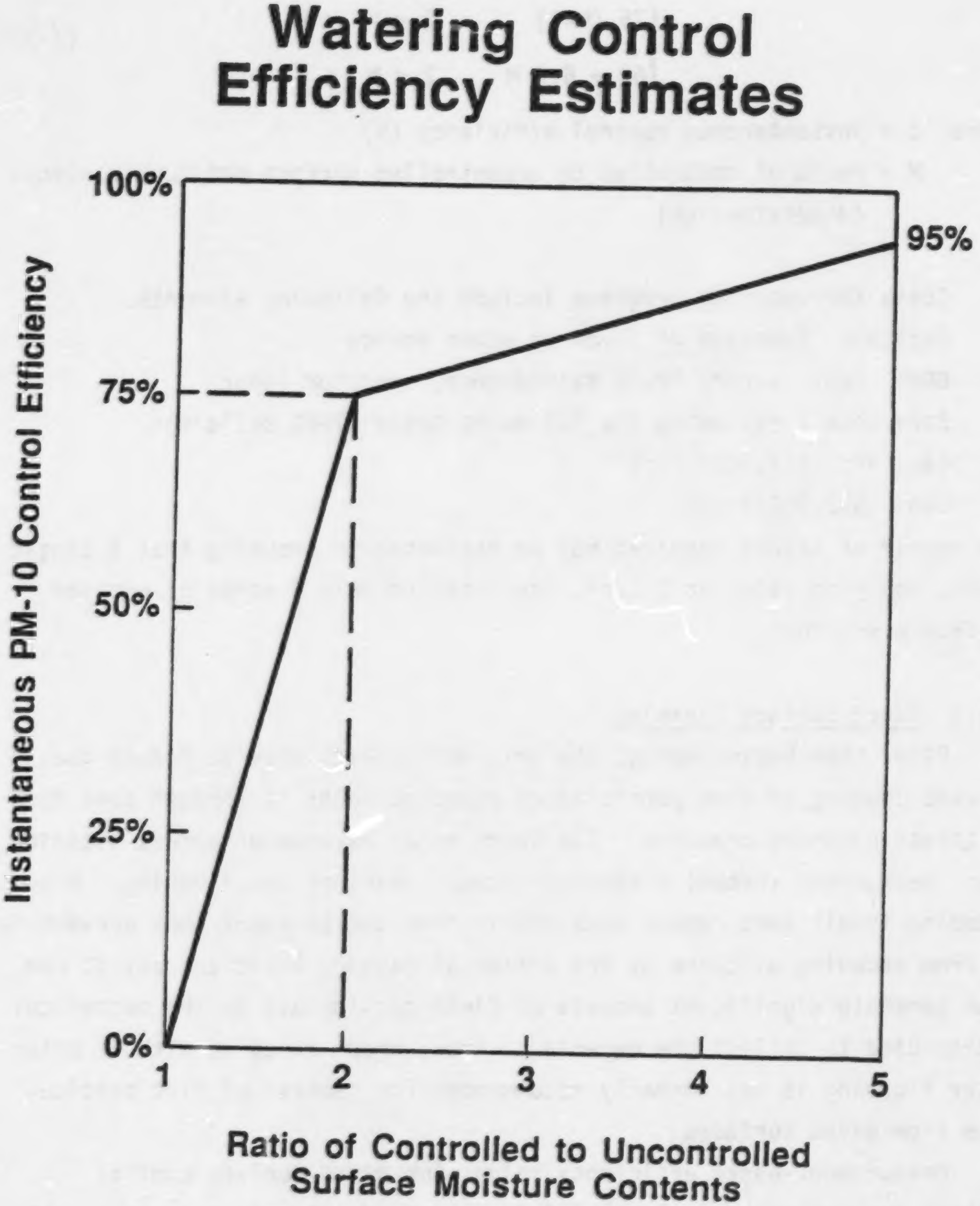


Figure 7-5. PM$_{10}$ control efficiency for watering unpaved surfaces.

Furthermore, this relationship is applicable to all size ranges considered:

$$c = \begin{cases} 75\ (M-1) & 1 \le M < 2 \\ 62 + 6.7\ M & 2 \le M \le 5 \end{cases} \qquad (7\text{-}11)$$

where c = instantaneous control efficiency (%)

M = ratio of controlled to uncontrolled surface moisture contents (dimensionless)

Costs for watering programs include the following elements:

Capital: Purchase of truck or other device

O&M: Fuel, water, truck maintenance, operator labor

Reference 2 estimates the following costs (1985 dollars):

Capital: $17,100/truck

O&M: $32,900/truck

The number of trucks required may be estimated by assuming that a single truck, applying water at 1 L/m², can treat roughly 4 acres of unpaved surface every hour.

7.4.5 Paved Surface Cleaning

Other than housekeeping, the only method available to reduce the surface loading of fine particles on paved surfaces is through some form of street cleaning practice. The three major methods of street cleaning are: mechanical (broom) cleaning; vacuum cleaning; and flushing. Broom sweeping itself does remove some debris from the pavement thus preventing it from becoming airborne by the action of passing vehicles; but it can also generate significant amounts of finer particulate by the mechanical action used to collect the material. Thus, broom sweeping without prior water flushing is not normally recommended for removal of fine particulate from paved surfaces.

Measurement-based efficiency values for paved surface control methods are presented in Table 7-3.[2] Note that all values in this table are for mitigative measures applied to industrial paved roads and reflect reductions in PM-15 not PM_{10}. It can be assumed, however, that similar reductions in gross PM_{10} may be expected for the surface cleaning methods listed in Table 7-3.

TABLE 7-3. MEASURED EFFICIENCY VALUES FOR PAVED SURFACE CONTROLS[a]

Method	Cited efficiency	Comments
Vacuum sweeping	0%-58%	Field emission measurement (PM-15) 12,000-cfm blower[b]
	46%	Based on field measurement of 30 μm particulate emissions
Water flushing	69-0.231 V[c,d]	Field measurement of PM-15 emissions[b]
Water flushing followed by broom sweeping	96-0.263 V[c,d]	Field measurement of PM-15 emissions[b]

[a] From Reference 2. All results based on measurements of air emissions from industrial paved roads.

[b] PM-10 control efficiency can be assumed to be the same as that tested.

[c] Water applied at 0.48 gal/yd².

[d] Equation yields efficiency in percent, V = number of vehicle passes since application.

Cost elements involved with vacuum sweeping include the following capital and O&M expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts, truck maintenance, and operator labor costs

Data presented in Reference 2 provides the following estimates for a vacuum sweeping program in April 1985 dollars:

Initial capital expense: $36,800/truck

Annual O&M expense: $34,200/truck

Determination of the number of trucks necessary can be made by assuming that one unit can sweep 6 mi/12 h.[2]

Finally, cost elements involved with flushing in combination with broom sweeping include the following capital and O&M expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts (possibly including brushes), truck maintenance, operator labor, water

Cost data presented in Reference 2 provides the following estimates for a flushing program:

Initial capital expense: $18,400/truck

Annual O&M expense: $27,600/truck

All costs are based on April 1985 dollars. Determination of the number of trucks required can be based on the assumption that 3 to 5 mi can be flushed or broom swept per unit per 8-h shift, respectively.[2]

7.5 PROCEDURES FOR COMPLIANCE DETERMINATION

In this section, two basic procedures will be discussed for the determination of dust control compliance for waste stabilization processes. These procedures are: permit systems; and indirect measures of control performance. Each is addressed below.

7.5.1 Permit Systems

The first approach to compliance determination involves the implementation and enforcement of a permit program for waste stabilization processes. This would generally be accomplished as part of the RCRA Part B permit for the site issued by the appropriate regulatory agency.

A permit system would require the site owner or operator to file a specific dust control plan with the appropriate regulatory agency having jurisdiction.

As part of the permit application, record keeping should be one of the main conditions for approval. Records of site activity and control should be submitted to the regulatory agency on a monthly basis. These records must be certified by a responsible party as to their completeness and accuracy. All site records should be permanently maintained by the agency.

To enforce the dust control plan submitted as part of the permit application, field audits of key control parameters should be made by regulatory personnel. The results of these audits would then be compared to site records for that period to determine compliance with permit conditions. If differences are found between application of the control(s) observed on-site and those recorded by site operating personnel, this would constitute a violation and would be grounds for further enforcement action. This approach is, however, predicated on the fact that strict implementation of the dust control plan will achieve certain reductions in PM_{10} emissions associated with site operation. General information to be included in a dust control plan, specific operational records, and general records to be kept by the source for each of the control measures discussed in Section 7.4 are provided below.[2]

7.5.1.1 Wind Fences/Barriers.

General Information

1. Locations of all raw materials storage and handling operations to be controlled with wind fences referenced on a plot plan available to the operator and regulatory personnel.
2. Physical dimensions of each source to be controlled and configuration of each fence or screen to be installed.
3. Physical characteristics of material to be handled or stored for each operation to be controlled by fence(s) or screen(s).
4. Applicable prevailing meteorological data (e.g., wind speed and direction) for site on an annual basis.

Specific Operational Records

1. Date of installation of wind fence or screen and initials of installer.

2. Location of installation relative to source and prevailing winds.

3. Type of material being handled and stored and physical dimensions of source controlled.

4. Date of removal of wind fence or screen and initials of personnel involved.

General Records

1. Fence or screen maintenance record.

2. Log of meteorological conditions for each day of site operation.

7.5.1.2 Capture/Collection Systems.

General Information

1. Locations of hood/enclosure, ductwork, and dust collector referenced on a plot plan available to the responsible party and regulatory personnel.

2. Plans, drawings, and specifications for storage silo(s), capture/collection system (including all available test data), and ancillary equipment.

3. Physical characteristics of all materials to be transferred to silos and stabilization process.

4. If a scrubber is used, source of water and chemical additives to be used, if any.

5. Location and type of permanently mounted instrumentation for monitoring operation of capture/collection system.

Specific Operational Records

1. Date of operation and operator's initials.

2. Start and stop time of dust control equipment.

3. Notations of malfunctions and corrective actions taken including date and time of each.

4. Type of material and number of loads or weight transferred to silo(s) and/or process between start and stop time.

5. Notations of any visible emissions from dust collector stack or vent including date and time of each event.

General Records

1. Equipment maintenance records.
2. Records of equipment malfunctions and downtime.
3. Purchase orders, etc., of maintenance supplies and replacement parts (e.g., bags, fan motors, etc.).

7.5.1.3 Wet Suppression.

General Information

1. Locations of all stabilized waste storage and handling operations referenced on plot plan of the site available to the operator and regulatory personnel.
2. Materials transport flow sheet which indicates the type of material (if variable), its handling and storage, size and composition of storage piles, etc.
3. The method and application intensity of water, etc., to be applied to the various materials and frequency of application, if not continuous.
4. Dilution ratio for chemicals added to water supply, if any.
5. Complete specifications of equipment used to handle the various materials and for wet suppression.
6. Source of water and chemical(s), if used.

Specific Operational Records

1. Date of operation and operator's initials.
2. Start and stop time of wet suppression equipment.
3. Location of wet suppression equipment.
4. Number of loads (or other measure of throughput) loaded between start and stop time.
5. Start and stop times for tank filling.

General Records

1. Equipment maintenance records.
2. Meteorological log of general conditions.
3. Records of equipment malfunctions and downtime.

7.5.1.4 Watering of Unpaved Surfaces.

General Information

1. All travel routes to be treated references on a plot plan available to both the site operator and regulatory personnel.

2. Length and area of surfaces to be watered.

3. Application intensity (L/m²) and frequency (a minimum moisture content may be specified as an alternative).

4. Type of application vehicle, capacity of tank, and source of water.

Specific Records to Be Kept by Site Operator

1. Equipment maintenance log.

2. Meteorological log of general conditions (e.g., sunny and warm vs. cloudy and cold).

3. Records of equipment breakdowns and downtime.

An example permanent record form which may be used to record the above information is shown in Figure 7-6.

Specific Records to Be Kept by Truck Operator

1. Date and time of treatment.

2. Equipment used (this should be referred back to dust control plan specifications).

3. Operator's initials (a separate operator's log may be kept and transferred later to permanent records by site operator).

4. Start and stop time, average speed, and number passes.

5. Start and stop time for filling of water tank.

7.5.1.5 Vacuum Surface Cleaning.

General Information

1. All road segments (and parking areas, if applicable) referenced on a map available to both the responsible party and the regulatory agency.

2. Length of each road (and area of each parking area).

3. Type of control applied to each road/area and planned frequency of application.

4. Any provisions for weather (e.g., ½ in of rainfall will be substituted for one treatment; etc.).

Date	Time	Application intensity (gal/yd²)	Area(s) treated	Climatic parameters		Equipment used	Operator initials	Comments
				Amb. temp. (°F)	Date/amt. of last rainfall			

Figure 7-6. Typical form for recording watering program control parameters.
(Sources: Unpaved surfaces, exposed areas, storage piles)

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets).

3. Start and stop times on a particular segment (or parking area), average speed, number of passed.

4. Qualitative description of surface loading before and after treatment.

5. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

General Records

1. Equipment maintenance records.

2. Meteorological log (to the extent that weather influences the control program--see above).

3. Any equipment malfunctions or downtime.

7.5.1.6 Flushing/Broom Surface Cleaning.

General Information

1. All road segments (and parking areas, if applicable) referenced on a map available to both the responsible party and the regulatory agency.

2. Length of each road (and area of each parking area).

3. Type of control applied to each road/area and planned frequency of application.

4. Provisions for weather (e.g., program suspended for periods of freezing temperatures).

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment.

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets).

3. Start and stop times on a particular segment (or parking area), average speed, number of passes.

4. Start and stop times for refilling tanks.

5. Qualitative description of surface loading before and after treatment.

6. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

General Records

1. Equipment maintenance records.

2. Meteorological log (to the extent that weather influences the control program--see above).

3. Any equipment malfunctions or downtime.

7.5.2 Indirect Measures of Control Performance

The final compliance format to be presented relates to various indirect measures of control performance. These could be used in conjunction with or in lieu of permit enforcement discussed above. They will, however, require more effort and expense to implement but should be at least somewhat defensible as measures of control efficiency.

The most obvious approach to indirectly measuring control performance involves the collection and analysis of material samples from the various dust-emitting sources. For example, if some form of paved surface cleaning is performed, collection of surface samples for silt content would indicate the efficacy of control for this particular source. The silt loadings obtained could be compared with "typical" surface loading values for similar uncontrolled surfaces to determine the degree of loading (and thus emissions) reductions achieved. This would, of course, necessitate the availability of a data base of "uncontrolled" silt loadings for comparison with site-specific data. The silt samples could also be chemically analyzed to determine the degree of contamination control being achieved.

Another indirect measure of control compliance is the collection and analysis of material samples from unpaved surfaces and stabilized waste storage and handling operations. In this case, analysis of the moisture content of these samples would indicate the amount of water applied and thus the degree of control achieved by wet suppression. Appropriate equations (presented above) would be used to determine control efficiency based on the sample data. Appropriate sampling and analysis methods to implement the above approach are included in Appendix D.

7.6 EXAMPLE CALCULATION

An example application of the emission estimation and control performance procedures for waste stabilization units is presented below. Although this example focuses on contaminant-specific (i.e., Cr) emissions, procedures are also provided for gross PM_{10} emissions as well.

7.6.1 Process Description

A commercial facility is located in a semiarid climate with 320 dry days per year. The facility operates 5 days per week (261 d/yr), 8 h/d, and processes the following listed waste streams likely to contain appreciable concentrations of chromium:

Waste Stream	Annual Receipts (Mg)
K001	1,000
F006	5,000

The characteristics of the waste are specified as:

Waste Stream	Cr Concentration (ppm by wt)
K001	200
F006	500

In the stabilization process, power plant fly ash is added to the liquid waste in sufficient quantities to obtain a 50% (weight) solids content in the stabilized waste. Fly ash is added to the liquid waste from elevated silos with the process equipment exposed to ambient winds. The stabilized waste is discharged directly into roll-offs which are carried by trucks across a 0.25 mile (0.40 km) of unpaved surface to the main plant road. Liquid waste is also delivered by trucks traveling across this same unpaved surface. A capture/collection system is used for control of raw materials transfer and handling and watering is used for control of vehicle-generated dust.

Since no site-specific S&A has been conducted, contamination of unpaved travel surfaces is assumed to be similar to that shown in Table 7-2. Silt content of the unpaved surface material is assumed to be identical to that shown in Table 7-1. All calculations are for annual average emissions rounded to two significant figures.

Based on facility records the following extent values are calculated:

Throughput of raw material:

$$(1{,}000 + 5{,}000)\ \frac{\text{Mg waste}}{\text{yr}} \times 1.0\ \frac{\text{Mg fly ash}}{\text{Mg waste}} = 6{,}000\ \frac{\text{Mg}}{\text{yr}}\ \text{fly ash}$$

Delivery of raw material: Assuming 41 Mg capacity tractor trailers

$$6{,}000\ \frac{\text{Mg}}{\text{yr}} \times \frac{1\ \text{load}}{41\ \text{Mg}} \times 0.8\ \frac{\text{km}}{\text{load}} = 120\ \text{km/yr}$$

Liquid waste delivery: Assuming 10,000 gal (37,850 L) capacity tank trucks and 8 lb/gal (0.96 kg/L) specific weight

$$37{,}850\ \frac{\text{L}}{\text{load}} \times 0.96\ \frac{\text{kg}}{\text{L}} \times \frac{1\ \text{Mg}}{1{,}000\ \text{kg}} = 36\ \frac{\text{Mg}}{\text{load}}$$

$$6{,}000\ \frac{\text{Mg waste}}{\text{yr}} \times \frac{1\ \text{load}}{36\ \text{Mg}} \times 0.8\ \frac{\text{km}}{\text{load}} = 130\ \text{km/yr}$$

Stabilized waste haulage: Assuming 5.5 Mg load capacity

$$(6{,}000\ \text{fly ash} + 6{,}000\ \text{liquid waste})\ \frac{\text{Mg waste}}{\text{yr}} \times \frac{1\ \text{load}}{5.5\ \text{Mg}} \times 0.8\ \frac{\text{km}}{\text{load}} = 1700\ \text{km/y}$$

Total truck traffic:

$$(120 + 130 + 1700)\ \text{km/yr} = 1950\ \text{km/yr}$$

7.6.2 Raw Material Handling

Assuming: Fly ash is pneumatically conveyed from trucks to silo(s).
Silo and discharge are ventilated to a baghouse dust collector (99.9% collection efficiency = 0.999)
The capture efficiency of the ventilated discharge is 95% (0.95).
The emissions are uncontaminated (no RCRA metals).

The uncontrolled emissions are calculated:

$$UE_{10} = 0.00085 \frac{\text{kg PM-10}}{\text{Mg fly ash}} \times 6{,}000 \frac{\text{Mg fly ash}}{\text{yr}} \times 2 \text{ transfers}$$

$$= 10 \text{ kg/yr uncontrolled PM-10 (or 5.1 kg/yr for each operation)}$$

The controlled emissions are calculated:

$$\text{Load-in--}0.00085 \frac{\text{kg}}{\text{Mg}} \times 6{,}000 \frac{\text{Mg}}{\text{yr}} \times (1-0.999) = 0.0051 \frac{\text{kg PM-10}}{\text{yr}}$$

(assumes 100% capture)

$$\text{Load-out--}\underbrace{[5.1 \times (1-0.95)] \frac{\text{kg}}{\text{yr}}}_{\text{(not captured)}} + \underbrace{[5.1 \times 0.95 \times (1-0.999)] \frac{\text{kg}}{\text{yr}}}_{\text{(not collected)}} = 0.26 \frac{\text{kg}}{\text{yr}}$$

$$\text{Total--}(0.26 + 0.0051) \frac{\text{kg PM-10}}{\text{yr}} = 0.26 \frac{\text{kg PM-10}}{\text{yr}} = CE_{10}$$

7.6.3 Vehicle Traffic on Unpaved Surfaces

Assuming: The gross weight of the delivery trucks is 59 Mg (65 tons).
The gross weight of the disposal trucks is 12 Mg (13 tons).
The vehicle speed is 24 km/h (15 mph).
Watering of unpaved surfaces is used at an application intensity of 2 L/m².
The annual vehicle traffic is 3000 vehicles/yr.

The uncontrolled emissions are calculated:

Waste and raw material delivery (stabilized waste) = 1,950 km/yr (total) - 1,700 km/yr

= 250 km/yr delivery traffic

Using the fractional proportion of waste and raw material traffic to total traffic (Section 7.6.1):

$$\text{Average vehicle weight (weighted based on vol.)} = \frac{250}{1950} \times 59 \text{ Mg} + \frac{1700}{1950} \times 12 \text{ Mg}$$

$$= 7.6 + 10 = 18 \text{ Mg}$$

$$\text{Average number of wheels (weighted based on vol.)} = \frac{250}{1950} \times 18 + \frac{1700}{1950} \times 10$$

$$= 2.3 + 8.7 = 11 \text{ wheels}$$

Therefore:

$$UE_{Cr} = \alpha \times 0.612 \times \frac{s}{12} \times \frac{S}{48} \times \left(\frac{W}{2.7}\right)^{0.7} \times \left(\frac{w}{4}\right)^{0.5} \times \frac{365-p}{365} \times \text{source extent}$$

$$= \frac{67}{1(10)^6} \times 0.612 \times \frac{18}{12} \times \frac{24}{48} \times \left(\frac{18}{2.7}\right)^{0.7} \times \left(\frac{11}{4}\right)^{0.5} \times \frac{320}{365} \times 1{,}950 \text{ veh-km/yr}$$

$$= 0.33 \frac{\text{kg Cr}}{\text{yr}} \text{ (or } 4{,}900 \frac{\text{kg total PM-10}}{\text{yr}}\text{)}$$

The controlled emissions are calculated assuming watering is conducted every 4 h ($t = 4$):

For e = mean annual pan evaporation (from Figure 7-4) = 90 in

p = potential average hourly daytime evaporation rate (from Eq. 7-7a)
$= 0.0049\ e = 0.0049\ (90) = 0.44$ mm/h

and d = average hourly traffic rate

$$= 3000 \frac{\text{vehicles}}{\text{yr}} \times \frac{1 \text{ yr}}{261 \text{ d}} \times \frac{1 \text{ d}}{8 \text{ h}} = 1.4 \frac{\text{vehicles}}{\text{h}}$$

Thus C = average control efficiency = $100 - \frac{0.8\ p\ d\ t}{i}$ (from Eq. 7-6)

$$= 100 - \left[\frac{0.8(0.44)(1.4)(4)}{2}\right] = 99\% = 0.99$$

Therefore:

$$CE_{Cr} = 0.33 \frac{\text{kg Cr}}{\text{yr}} \times (1 - 0.99) = 0.0033 \frac{\text{kg Cr}}{\text{yr}} \text{ or}$$

$$CE_{10} = 4{,}900 \frac{\text{kg PM-10}}{\text{yr}} \times (1 - 0.99) = 49 \frac{\text{kg PM-10}}{\text{yr}} \text{ total emissions}$$

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APPENDIX A.

OPEN DUST SOURCE EMISSION FACTOR RATING AND CONTROL EFFICIENCY TERMINOLOGY

APPENDIX A. OPEN DUST SOURCE EMISSION FACTOR RATING AND CONTROL EFFICIENCY TERMINOLOGY

A.1 EMISSION FACTOR RATING TERMINOLOGY

In AP-42, the reliability of emission factors is indicated by an overall Emission Factor Rating ranging from A (excellent) to E (poor). These ratings take into account the type and amount of data from which the factors were calculated. Note that measurements underlying each emission factor are rated on a similar scale of A to D.

The use of a statistical confidence interval may seem desirable as a more quantitative measure of the reliability of an emission factor. Because of the way an emission factor data base is generated, however, prudent application of statistical procedures precludes the use of confidence intervals unless the following conditions are met:

- The sample of sources from which the emission factor was determined is representative of the total population of such sources.
- The data collected at an individual source are representative of that source (i.e., no temporal variability resulting from source operating conditions could have biased the data).
- The method of measurement was properly applied at each source tested.

Because of the almost impossible task of assigning a meaningful confidence limit to the above variables and to other industry-specific variables, the use of a statistical confidence interval for an emission factor is not practical.

The following emission factor ratings are applied to the emission factors:

A - Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.

B - Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

C - Average. Developed only from A- and B-rated data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

D - Below average. The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E - Poor. The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There may be evidence of variability within the source category population.

Limitations on the use of these factors are always footnoted. Because the application of these factors is somwhat subjective, the reasons for each rating are documented in the background files maintained by the Office of Air Quality Procedures and Standards (OAQPS).

A.2 CONTROL EFFICIENCY TERMINOLOGY

Some control techniques often used for open dust sources begin to decay in efficiency almost immediately after implementation. The most extreme example of this is the watering of unpaved roads where the efficiency decays from nearly 100 percent to 0 in a matter of hours (or minutes). The control efficiency for broom sweeping and flushing applied in combination on a paved road may decay to zero in 1 or 2 days. Chemical dust suppressants applied to unpaved roads can yield control efficiencies that will decay to zero in several months. Consequently, a single-valued control efficiency is usually not adequate to describe the performance of most intermittent control techniques for open dust sources. The control efficiency must be reported along with a time period over which the value applies. For continuous control systems (e.g., wet suppression for materials transfer), a single control efficiency is usually appropriate.

Certain terminology has been developed to aid in describing the time dependence of open dust control efficiency. These terms are:

1. Control lifetime is the time period (or amount of source activity) required for the efficiency of an open dust control measure to decay to zero.

2. Instantaneous control efficiency is the efficiency of an open dust control at a specific point in time.

3. Average control efficiency is the efficiency of an open dust source control averaged over a given period of time (or number of vehicle passes).

From the above definitions, it is clear that average control efficiency is related to instantaneous control efficiency by the following general equation:

$$C(X) = \frac{1}{X} \int_0^X c(x)dx$$

where: x = time (or number of vehicle passes) after application
X = time (or number of vehicle passes) over which an average efficiency is desired
c = instantaneous control efficiency
C = average control efficiency

Field tests of certain paved and unpaved road dust controls indicate that instantaneous control efficiency may be adequately represented as a linear function of time (or vehicle passes):

$$c(x) = a-bx$$

where a and b are constants, and $b \geq 0$. In that case, average control efficiency is given by

$$c(X) = a \frac{b}{2}X$$

APPENDIX B

ESTIMATION OF CONTROL COSTS AND COST EFFECTIVENESS

Relative costs of alternative control measures are used in the development and evaluation of particulate fugitive emissions control strategies. Cost analyses are used by control agency personnel to develop overall strategies or to evaluate plant specific control strategies. Industry personnel perform cost analyses to evaluate control alternatives for a specific source or to develop a plant-wide emissions control strategy. Although the specifics of these analyses may vary depending upon the objective of the analysis and the availability of cost data, the general format is similar.

The primary goal of any cost analysis is to provide a consistent comparison of the real costs of alternative control measures. The objective of this section is to provide the reader with a methodology that will allow such a comparison. It will describe the overall structure of a cost analysis and provide the resources for conducting the analyses. Because cost data are continuously changing, specific cost data are not provided. However, sources of cost information and mechanisms for cost updating are provided.

The approach outlined in this section will focus on cost effectiveness as the primary comparison tool. Cost effectiveness is simply the ratio of the annualized cost of the emissions control to the amount of emissions reduction achieved. Mathematically, cost effectiveness is defined by:

$$C^* = \frac{C_a}{\Delta R} \qquad \text{(B-1)}$$

where: C^* = cost effectiveness, \$/mass of emissions reduction
C_a = annualized cost of the control measure, \$/yr
ΔR = reduction (mass/yr) in annual emissions

This general methodology was chosen because it is equally applicable to different controls that achieve equivalent emissions reduction on a single source and to measures that achieve varied reductions over multiple sources.

The discussion is divided into three sections. The first section describes the general cost analysis methodology, including the various types of costs that should be considered and presents methods for calculating those costs. The second identifies the primary cost elements associated with each of the fugitive emissions control systems. The final section identifies sources of cost data and discusses methods for updating cost data to constant dollars, and includes example calculation cases for estimating costs and cost effectiveness.

B.1 GENERAL COST METHODOLOGY

Calculation of cost effectiveness for comparison of control measures or control strategies can be accomplished in four steps. First, the alternative control/cost scenarios are selected. Second, the capital costs of each scenario are calculated. Third, the annualized costs for each of the alternatives are developed. Finally, the cost effectiveness is calculated, taking into consideration the level of emissions reduction.

The general approach for performing each of the above steps is described below. This approach is intended to provide general guidance for cost comparison. It should not be viewed as a rigid procedure that must be followed in detail for all analyses. The reader may choose or may be forced through resource or informational constraints to omit some elements of the analysis. However, for comparisons to be valid, cautions that should be observed are: (1) all control scenarios should be treated in the same manner, and (2) cost elements that vary radically between cost scenarios should not be omitted.

B.1.1 Select Control/Cost Scenarios

Prior to the cost analysis, general control measures or strategies will have been identified. These measures or strategies will fall into one of the major classes of fugitive emission control techniques that were identified. The first step in the cost analysis is to select a set of specific control/cost scenarios from the general techniques. The specific scenarios will include definition of the major cost elements and identification of specific implementation alternatives for each of the cost elements.

Each of the general control techniques identified in this document has several major cost elements. The first step in any cost analysis is definition of these major cost elements. These elements include capital equipment elements and operation/maintenance elements. Information is provided in Section B.2 on the major cost elements associated with each of the general control techniques. For example, the major cost elements for chemical stabilization of an unpaved road include: (a) chemical acquisition; (b) chemical storage; (c) road preparation; (d) mixing the chemical with water; and (e) application of the chemical solution.

For each major cost element, several implementation alternatives can be chosen. Options within each cost element include such choices as buying or renting equipment; shipping chemicals by railcar, truck tanker, or in drums via truck; alternative sources of power or other utilities; and use of plant personnel or contractors for construction and maintenance. The major cost elements and the implementation alternatives for each of these elements for the chemical stabilization example described above are outlined in Table B-1.

Note that the following discussion is applicable only to "in-house" open fugitive dust control programs. Many industrial facilities prefer to retain outside contractors to implement paved and unpaved road dust control programs. Some contractors provide complete services, from ordering and storing raw materials through control application; others may only supply the vehicles and drivers required for application. As a result, the reader may need to consider several implementation alternatives (such as those given in Table B-1) prior to selection of a cost-efficient dust control program.

B.1.2 Develop Capital Costs

The capital costs of an open dust emissions control program are those direct and indirect expenses incurred up to the date when the program is implemented. These capital costs include actual purchase expenses for capital equipment, labor and utility costs associated with installation of the control system, and system startup and shakedown costs. In general, direct capital costs are the costs of control

TABLE B-1. IMPLEMENTATION ALTERNATIVES FOR STABILIZATION OF AN UNPAVED ROAD

Cost elements/implementation alternatives

I. Purchase and Ship Chemical

A. Ship in railcar tanker (11,000 to 22,000 gal/tanker)
B. Ship in truck tanker (4,000 to 6,000 gal/tanker)
C. Ship in drums via truck (55 gal/drum)

II. Store Chemical

A. Store on plant property
1. In new storage tank
2. In existing storage tank
a. Needs refurbishing
b. Needs no refurbishing
3. In railcar tanker
a. Own railcar
b. Pay demurrage
4. In truck tanker
a. Own truck
b. Pay demurrage
5. In drums
B. Store in contractor tanks

III. Prepare Road

A. Use plant-owned grader to minimize ruts and low spots
B. Rent contractor grader
C. Perform no road preparation

IV. Mix Chemical and Water in Application Truck

A. Put chemical in spray truck
1. Pump chemical from storage tank or drums into application truck
1. Pour chemical from drums into application truck, generally using forklift
B. Put water in application truck
1. Pump from river or lake
2. Take from city water line

V. Apply Chemical Solution via Surface Spraying

A. Use plant owned application truck
B. Rent contractor application truck

materials and equipment as well as the labor and utilities needed to install the equipment. Indirect costs are overall costs to the facility incurred by the system but not directly attributable to specific equipment items.

Direct costs cover the purchase of equipment and auxiliaries and the costs of installation. Capital costs also include any cost of site development necessitated by the control system. For example, if the storage tanks for chemical unpaved road dust suppressants require that an access road be constructed, this access road is included as a capital expense. The types of direct costs for typical fugitive emissions control programs at TSDFs are associated with items such as vehicles (e.g., spray or flusher trucks) and storage tanks, pumps, and piping.

Indirect costs cover the expenses not attributable to specific equipment items. Items in this category include:

1. Engineering costs--including administrative, project, and general; labor and other costs associated with specification of the control program parameters; cost analysis; purchasing and accounting; consultant services.

2. Field and construction expenses--includes equipment rental, repair, fuel, or lubricants; costs associated with grading or other road preparation; field supervision; storage areas.

3. Shakedown/startup--includes costs associated with control startup and shakedown.

4. Contingency costs--the excess account set up to deal with uncertainties in the cost estimate, including unforeseen escalation in prices, malfunctions, equipment design alterations, and similar sources.

The values for these items will vary depending on the specific operations to be controlled and the types of control systems used. Typical ranges for indirect costs[1] based on the total installed cost of the capital equipment are shown in Table B-2.

B.1.3 Determine Annualized Costs

The most common basis for comparison of an alternative control system is that of annualized cost. The annualized cost of a fugitive emission control system includes operating costs such as labor, TABLE B-2. TYPICAL VALUES FOR INDIRECT CAPITAL COSTS

Cost item	Ranges of values
Engineering	8 to 20 percent of installed cost. High value for small projects; low value for large projects
Construction and field expenses	7 to 70 percent of installed cost
Contractor's fee	10 to 15 percent of installed cost
Shakedown/startup	1 to 6 percent of installed cost
Contingency	10 to 30 percent of total direct and indirect costs dependent upon accuracy of estimate. Generally, 20 percent is used in a study estimate

Source: Reference 1.

materials, utilities, and maintenance items as well as the annualized cost of the capital equipment. The annualization of capital costs is a classical engineering economics problem, the solution of which takes into account the fact that money has time value. These annualized costs are dependent on the interest rate paid on borrowed money or collectable by the plant as interest (if available capital is used), the useful life of the equipment and depreciation rates of the equipment.

The components of the annualized cost of implementing a particular control technique are depicted graphically in Figure B-1. Purchase and installation costs include freight, sales tax, and interest on borrowed money. The operation and maintenance costs reflect increasing frequency of repair as the equipment ages along with increased costs due to inflation for parts, energy, and labor. On the other hand, costs recovered by claiming tax credits or deductions are considered as income. Mathematically the annualized costs of control equipment can be calculated from:

$$C_a = CRF\ (C_p) + C_o + 0.5\ C_o \tag{B-2}$$

where: C_a = annualized costs of control equipment, \$/yr
CRF = Capital Recovery Factor, 1/yr
C_p = installed capital costs, \$
C_o = direct operating costs, \$/yr
0.5 = plant overhead factor

The various components of this equation are briefly described below.

The annualized cost of capital equipment is calculated by using a capital recovery factor (CRF). The CRF combines interest on borrowed funds and depreciation into a single factor. It is a function of the interest rate and the overall life of the capital equipment and can be estimated by the following equation:

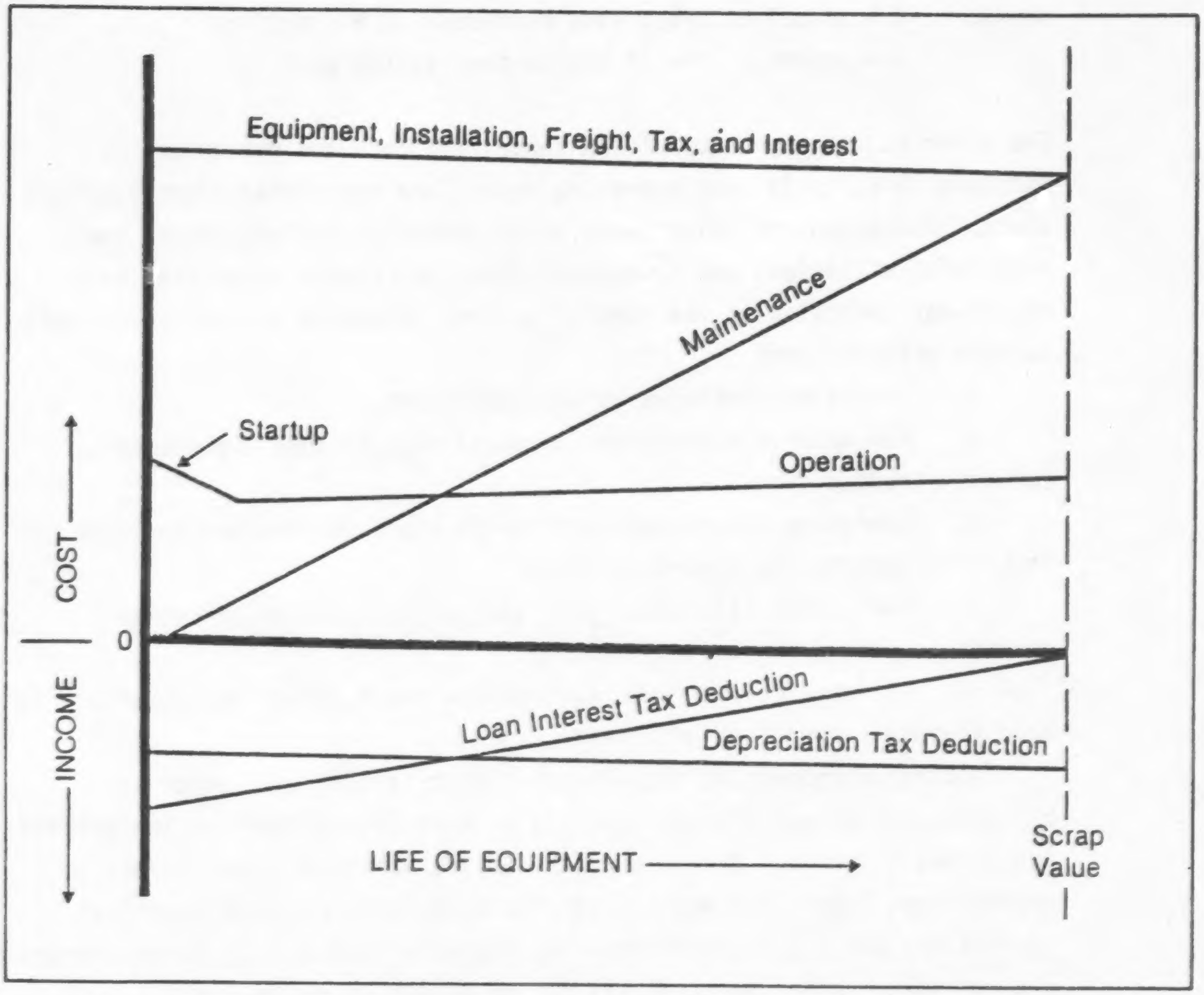

Figure B-1. Graphical presentation of fugitive emission control costs.

$$CRF = \frac{i(1+i)^n}{(1+i)^n-1} \qquad (B-3)$$

where: i = annual interest rate expressed as a fraction

n = economic life of the control system (yr)

The other major components of the annualized cost are operation and maintenance costs (direct operating costs) and associated plant overhead costs. Operation and maintenance costs generally include labor, raw materials, utilities, and by-product costs or credits associated with day-to-day operation of the control system. Elements typically included in this category are:

1. Utilities--includes water, electricity.
2. Raw materials--includes chemical unpaved dust suppressants, surfactants, etc.
3. Operating labor--includes supervision, skilled and unskilled labor required by the control program.
4. Fuel costs--includes fuel required by vehicles and other equipment used in the control program.
5. Maintenance and repairs--includes the manpower and materials to keep equipment operating efficiently.

Another component of the operating cost is overhead, which is a business expense not charged directly to a particular part of the process but allocated to it. Overhead costs include administrative, safety, engineering, legal, and medical services; payroll, employee benefits; recreation; and public relations. As suggested by Eq. B-2, these charges are estimated to be approximately 50% of direct operating costs.

B.1.4 Calculate Cost Effectiveness

As discussed in the introduction to this section the most informative method for comparing control measures or control strategies for particulate fugitive emissions sources is on a cost-effectiveness basis. Mathematically, cost effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R} \qquad \text{(B-1)}$$

where: C^* = cost effectiveness, \$/mass of emissions reduction
C_a = annualized cost of the control measure, \$/yr
ΔR = reduction (mass/yr) in annual emissions

The annualized cost of control equipment can be calculated using Eq. B-2. The annual reduction in particulate emissions can be calculated from the following equation:

$$\Delta R = M\ e\ c \qquad \text{(B-4)}$$

where: M = annual source extent
e = uncontrolled emission factor (i.e., mass of uncontrolled emissions per unit of source extent)
c = average control efficiency expressed as a fraction

B.2 COST ELEMENTS OF FUGITIVE EMISSIONS CONTROL SYSTEMS

The cost methodology outlined in Section B.1 requires that the analyst define and select alternative control/cost scenarios and develop costs for the major cost elements within these scenarios. The objective of this subsection is to assist the reader in identifying the implementation alternatives and major cost elements associated with the emission reduction techniques. For open dust sources, the control techniques addressed are: wet dust suppression, surface cleaning, and paving.

Implementation alternatives for open dust source emission control measures are presented in Tables B-3 through B-5. Table B-3 presents implementation alternatives for water and chemical dust suppressant systems. Table B-4 presents alternatives for three types of street cleaning systems--vacuuming, flushing, and a combination of flushing and broom sweeping. Table B-5 presents alternatives for streets or parking lot paving.

After the control scenarios are selected, the analyst must estimate the capital cost of the installed system and the operating and maintenance costs. The indirect capital costs elements are common to all systems and were identified in Table B-2. The direct capital cost elements and direct operation and maintenance cost elements which are unique to each type of fugitive emission control system are identified in Tables B-6 through B-9. These costs are provided for dust suppressant programs for open dust sources in Table B-6, street cleaning programs in Table B-7, paving in Table B-8, and wet suppression systems for process sources in Table B-9.

B.3 SOURCES OF COST DATA

Collection of the data to conduct a cost analysis can sometimes be difficult. If a well defined system is being costed, the best sources of accurate capital costs are vendor estimates. However, if the system is not sufficiently defined to develop vendor estimates, published cost data can be used. Cost data are available for both paved and unpaved roads in References 2 through 8.

Often published cost estimates are based on different time-valued dollars. These estimates must be adjusted for inflation so that they reflect the most probable capital investments for a current time and can be consistently compared. Capital cost indices are the techniques used for updating costs. These indices provide a general method for updating overall costs without having to complete in-depth studies of individual cost elements. Indices that typically are used for updating control system costs are the Chemical Engineering Plant Cost Index (available in any issue of *Chemical Engineering Magazine*), the Bureau of Labor Statistics Metal Fabrication Index, and the Commerce Department Monthly Labor Review.

TABLE B-3. IMPLEMENTATION ALTERNATIVES FOR DUST SUPPRESSANTS APPLIED TO AN UNPAVED ROAD

Program implementation alternative	Dust suppressant type	
	Chemicals	Water
I. Purchase and Ship Dust Suppressant		
A. Ship in railcar tanker (11,000 to 22,000 gal/tanker)	X	
B. Ship in truck tanker (4,000 to 6,000 gal/tanker)	X	
C. Ship in drums via truck (55 gal/drum)		
II. Store dust suppressant		
A. Store on plant property		
1. In new storage tank	X	
2. In existing storage tank	X	
a. Needs refurbishing	X	
b. Needs no refurbishing	X	
3. In railcar tanker		
a. Own railcar	X	
b. Pay demurrage	X	
III. Prepare Road		
A. Use plant-owned grader to minimize ruts and low spots	X	X
B. Rent contractor grader	X	X
C. Perform no road preparation	X	X
IV. Mix Dust Suppressant/Water in Application Truck		
A. Put suppressant in spray truck		
1. Pump suppressant from storage tank or drums into application truck	X	
2. Pour suppressant from drums into application truck, generally using forklift	X	
B. Put water in application truck		
1. Pump from river or lake	X	X
2. Take from city water line	X	X
V. Apply suppressant solution via surface spraying		
A. Use plant owned application truck	X	X
B. Rent contractor application truck	X	X

TABLE B-4. IMPLEMENTATION ALTERNATIVES FOR PAVED ROAD CLEANING

Program implementation alternative	Vacuum sweeping	Flushing	Flushing and broom sweeping
I. Acquire Flusher and Driver			
A. Purchase flusher/sweeper and use plant driver		X	X
B. Rent flusher/sweeper and driver		X	X
C. Use existing unpaved road watering truck		X	
II. Acquire Vacuum Sweeper and Driver			
A. Purchase sweeper and use plant driver	X		
B. Rent sweeper and driver	X		
III. Fill Flusher Tank With Water			
A. Pump water from river or lake		X	X
B. Take water from city line		X	X
IV. Maintain Purchased Flusher		X	X
V. Maintain Purchased Vacuum Sweeper	X		X

TABLE B-5. IMPLEMENTATION ALTERNATIVES FOR PAVING

Program implementation alternative
I. Excavate Existing Surface to Make Way for Base and Surface Courses
A. 2-in. depth
B. 4-in. depth
C. 6-in depth
II. Fine Grade and Compact Subgrade
III. Lay and Compact Crushed Stone Base Course
A. 2-in. depth
B. 4-in. depth
C. 6-in depth
IV. Lay and Compact Hot Mix Asphalt (Probably AC120-150) Surface Course
A. 2-in. depth
B. 4-in. depth
C. 6-in depth

TABLE B-6. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR DUST SUPPRESSANT SYSTEMS[a] (Open Sources)

Capital equipment

- Storage equipment
    - Tanks
    - Railcar
    - Pumps
    - Piping
- Application equipment
    - Trucks
    - Spray system
    - Piping (including winterizing)

O&M expenditures

- Utility or fuel costs
    - Water
    - Electricity
    - Gasoline or diesel fuel
- Supplies
    - Chemicals
    - Repair parts
- Labor
    - Application time
    - Road conditioning
    - System maintenance

---

[a] Not all items are necessary for all systems. Specific items are dependent on the control scenario selected.

TABLE B-7. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR STREET CLEANING

Capital equipment

- Sweeping
    - Broom
    - Vacuum system
- Flushing
    - Piping
    - Flushing truck
    - Water pumps

O&M expenditures

- Utility and fuel costs
    - Water
    - Gasoline or diesel fuel
- Supplies
    - Replacement brushes
- Labor
    - Sweeping or flushing operation
    - Truck maintenance
- Waste disposal

TABLE B-8. CAPITAL EQUIPMENT AND O&M EXPENDITURES ITEMS FOR PAVING

Capital equipment

- Operating equipment
  - Graders
  - Paving application equipment
  - Materials
  - Paving material (asphalt or concrete)
  - Base material

O&M expenditures

- Supplies
  - Patching material
- Labor
  - Surface preparation
  - Paving
  - Road maintenance
  - Equipment maintenance

TABLE B-9. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SUPPRESSION SYSTEMS (PROCESS SOURCES)

Capital equipment

- Water spray systems
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units

- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity

- Supplies
  - Surfactant
  - Screens

- Labor
  - Maintenance
  - Operation

Operation and maintenance cost estimates typically are based on vendor or industry experience with similar systems. In the absence of such data, rough estimates can be developed from References 4 and 7.

B.4 EXAMPLE CALCULATIONS

Table B-10 lists the steps necessary to calculate the cost effectiveness for two control alternatives for stabilizing unpaved travel surfaces. An example problem illustrating the calculations is presented in Table B-11. Tables B-12 through B-15 are referenced in the calculations of Tables B-10 and B-11.

REFERENCES FOR APPENDIX B

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2. Cuscino, T., Jr., G. E. Muleski, and C. Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110, NTIS No. PB84-110568, U.S. Environmental Protection Agency, Research Triangle Park, NC. October 1983.
3. Muleski, G. E., T. Cuscino, Jr., and C. Cowherd, Jr. Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry. EPA-600/2-84-027, NTIS No. PB84-154350, U.S. Environmental Protection Agency, Research Triangle Park, NC. February 1984.
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6. Robert Snow Means Company, Inc. Building Construction Cost Data. 1979.
7. Neveril, R. V. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA-450/5-80-002. GARD, Inc. December 1978.
8. Turner, J. H., et al. Fugitive Particulate Emissions from Hazardous Waste Sites. Prepared for the U.S. Environmental Protection Agency under Contract No. 68-03-3149, Cincinnati, Ohio. September 1984.

TABLE B-10. COST AND COST-EFFECTIVENESS ESTIMATION FOR CHEMICAL STABILIZATION OF AN UNPAVED ROAD

This table lists the steps necessary to calculate the cost-effectiveness for two control alternatives for stabilizing unpaved travel surfaces.

Step 1--Specify Desired Average Control Efficiency (e.g., 50, 75, or 90 percent)

Step 2--Specify Basic Vehicle, Road and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics include:

1. Average Daily Traffic (ADT)--this is the number of vehicles using the road regardless of direction of travel (e.g., on a two-lane road in an iron and steel plant, 100 vehicles in one direction, and 100 in the other direction during a single day yields 200 ADT);
2. Average vehicle weight in short tons;
3. Average number of vehicle wheels; and
4. Average vehicle speed in mph.

Required road characteristics include:

1. Actual length of roadway to be controlled in miles;
2. Width of road to be controlled;
3. Silt content (in percent)--for an existing road, these values should be measured; however, for a proposed plant, average values shown in AP-42 can be used;
4. Surface loading (for paved roads) in lb/mile--this is the total loading on all traveled lanes rather than the average lane loading; and
5. Bearing strength of the road--At this time, just a visual estimate of low, moderate, or high is required.

Required climatological characteristics (applicable only to watering of unpaved roads): potential evaporation in mm/h--the value depends on both the location and the month of concern. Control efficiency data in this report for watering unpaved roads assume a location in Detroit, Michigan, in the summer.

Step 3--Calculate the Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

The emission factor (E) should be calculated using the equations from AP-42.

The annual source extent (SE) is calculated as 365 x ADT x average one way trip distance.

Step 4--Consult the Appropriate Control Program Design Table to Determine the Time Between Applications and the Application Intensity

Select the appropriate table

Control technique	Table containing information
Coherex® applied to unpaved roads	Table B-12
Petro Tac applied to unpaved roads	Table B-13

(continued)

TABLE B-10. (continued)

Verify that the vehicle and road characteristics listed in Step 2 are similar to those listed in the footnotes of the selected table. If they are significantly different, the table cannot be used.

Step 5--Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Application (from Step 4)

Step 6--Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

Step 7--Consult the Appropriate Program Implementation Alternatives Table and Select the Desired Program Implementation Plan

Control technique	Table containing information
Coherex® applied to unpaved roads	Table B-14
Petro Tac applied to unpaved roads	Table B-15

Step 8--Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

To annualize capital investment, the capital cost is multiplied by a capital recovery factor which is calculated as follows:

$$CRF = [i(1 + i)^n] / [(1 + i)^n - 1]$$

where CRF = capital recovery factor
i = annual interest rate fraction
n = number of payment years

Scale total annual cost by ratio of actual road width in feet divided by 40 ft.

Step 9--Calculate Cost-Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by Desired Control Efficiency Fraction (from Step 1)

TABLE B-11. EXAMPLE CALCULATION CASE: APPLICATION OF COHEREX® TO AN UNPAVED ROAD

This table is an example cost-effectiveness calculation for controlling PM_{10} using Coherex® on an unpaved road in a Detroit, Michigan, plant.

Step 1--Specify Desired Average Control Efficiency

Desired average control efficiency = 90 percent

Step 2--Specify Basic Vehicle, Road, and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics:

1. Average daily traffic = 100 vehicles per day;
2. Average vehicle weight = 40 ST;
3. Average number of vehicle wheels = 6; and
4. Average vehicle speed = 20 mph

Required road characteristics:

1. Actual length of roadway to be controlled = 6.3 miles;
2. Width of roadway = 30 ft;
3. Silt content = 9.1 percent;
4. Bearing strength of road = moderate

Step 3--Calculate Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

$$E = k\ 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$$

where E = emission factor
k = 0.36 for PM_{10} (from Section 2.0 of this manual)
s = 9.1 percent (given in Step 2)
S = 20 mph (given in Step 2)
W = 40 ST (given in Step 2)
w = 6 (given in Step 2)
p = 140 (as per Figure 2-4 for Detroit, Michigan)

E = 4.98 lb/VMT

SE = 365 × ADT × average one-way trip distance

$$SE = 365\ \frac{\text{days}}{\text{year}} \times 100\ \frac{\text{vehicles}}{\text{day}} \times \frac{6.3\ \text{miles}}{2\ \text{vehicle}}$$

SE = 115,000 VMT/year

Emission rate = E × SE

$$\text{Emission rate} = 4.98\ \text{lb/VMT} \times 115{,}000\ \text{VMT/year} \times \frac{1\ \text{short ton}}{2{,}000\ \text{lb}}$$

Emission rate = 286 tons of PM_{10} per year

(continued)

TABLE B-11. (continued)

Step 4--Consult the Appropriate Control Program Design Table to Determine the Times Between Applications and the Application Intensity

Use Table B-12.

The vehicle and road characteristics listed in Step 2 are similar to those in the footnotes of Table 2-1.

From Table B-12:

Application intensity = 0.83 gal. of 20 percent solution/yd^2 (initial application)

= 1.0 gal. of 12 percent solution/yd^2 (reapplication)

Application frequency = once every 47 days

Step 5--Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Applications (from Step 4)

$$\text{No. of annual applications} = \frac{365}{47} = 77.7 \ \frac{\text{applications}}{\text{year}}$$

Step 6--Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

$$\text{No. of treated miles per year} = 6.3 \text{ miles} \times 7.77 \ \frac{\text{applications}}{\text{year}}$$

= 49 treated miles/year

Step 7--Consult the Appropriate Program Implementation Alternatives Tables and Select the Desired Program Implementation Plan

From Table B-13, the following implementation plan and associated costs are anticipated:

Selected alternative	Cost		
	Capital investment, $	Unit cost	
		$/Treated mile	$/Actual mile
1. Purchase Coherex® and ship in truck tanker		4,650	
2. Store in newly purchased storage tank	30,000		
3. Prepare road with plant owned grader			630
4. Pump water from river or lake	5,000	135	
5. Apply chemical with plant owned application truck (includes labor to pump water and Coherex® and apply solution)	70,000		
	105,000	4,785	630

(continued)

TABLE B-11. (continued)

Step 8--Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

Calculate annual capital investment (PI) = capital investment x CRF

$CRF = [i(1 + i)^n]/[(1 + i)^n - 1]$
CRF = capital recovery factor
$i = 0.15$
$n = 10$ years
$CRF = 0.199252$
$PI = 105{,}000 \times 0.199252 = \$20{,}900/\text{year}$

Calculate annual operation and maintenance cost (MO)

$$MO = \$4{,}785/\text{treated mile} \times 49 \text{ treated miles/year} + \$630/\text{actual mile} \times 6.3 \frac{\text{actual miles}}{\text{year}}$$
$$= \$238{,}000/\text{year}$$

Calculate total cost (D) = PI + MO

$D = \$20{,}900/\text{year} + \$238{,}000/\text{year}$
$= \$258{,}900/\text{year}$

Scale total cost by actual road width

$$\text{Actual total cost for a 30-ft wide road} = \$258{,}900/\text{yr} \times \frac{30 \text{ ft}}{40 \text{ ft}}$$
$$= \$194{,}200/\text{yr}$$

Step 9--Calculate Cost-Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by the Desired Control Efficiency Fraction (from Step 1)

$$\text{Cost effectiveness} = \frac{\$194{,}200/\text{year}}{286 \text{ ST/year} \times 0.9}$$
$$= \$754/\text{short ton of } PM_{10} \text{ reduced}$$

TABLE B-12. ALTERNATIVE CONTROL PROGRAM DESIGN FOR COHEREX® APPLIED TO TRAVEL SURFACES[a] [b]

Average percent control desired	Vehicle passes between applications	Days between applications as a function of ACT		
		100	300	500
50	23,300	233	78	47
75	11,600	116	39	23
90	4,650	47	16	9

[a] Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application:
- 3.7 L of 20 percent solution/m^2 (0.83 gallon of 20 percent solution/yd^2) initial application
- 4.5 L of 12 percent solution/m^2 (1.0 gal. of 12 percent solution/yd^2); reapplications

Vehicular traffic:
- Average weight--Mg (43 tons)
- Average wheels--6
- Average speed--29 km/h (20 mph)

Road structure: bearing strength--low to moderate

[b] PM-10 = Particles ≤10 μmA.

[c] For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

TABLE B-13. ALTERNATIVE CONTROL PROGRAM DESIGN FOR PETRO TAC APPLIED TO TRAVEL SURFACES[a b]

Average percent control desired	Vehicle passes between applications	Days between applications as a function of ACT		
		100	300	500
50	92,000	920	307	184
75	47,800	478	159	96
90	21,200	212	71	42

[a] Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application: 3.2 L of 20 percent solution/m² (0.7 gal of 20 percent solution/yd²); each application

Vehicular traffic:

- Average weight--Mg (30 tons)
- Average wheels--9.2
- Average speed--22 km/h (15 mph)

Road structure: bearing strength--low to moderate

[b] PM-10 = particles <10 μmA.

[c] For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

TABLE B-14. IDENTIFICATION AND COST ESTIMATION OF COHEREX® CONTROL ALTERNATIVES

Program implementation alternatives	Cost
I. Purchase and ship Coherex®	
A. Ship in railcar tanker (11,000-22,000 gal/tanker)	$4,650/treated mile
B. Ship in truck tanker (4,000-6,000 gal/tanker)	$4,650/treated mile
C. Ship in drums via truck (55 gal/drum)	$7,040/treated mile
II. Store Coherex®	
A. Store on plant property	
1. In new storage tank	$30,000 capital
2. In existing storage tank	
a. Needs refurbishing	$5,400 capital
b. Needs no refurbishing	-0-
3. In railcar tanker	
a. Own railcar	-0-
b. Pay demurrage	$20, $30, $60/treated mile
4. In truck tanker	
a. Own truck	-0-
b. Pay demurrage	$70/treated mile
5. In drums	-0-
B. Store in contractor tanks	$140/treated mile
III. Prepare road	
A. Use plant-owned grader to minimize ruts and low spots	$630/actual mile
B. Rent contractor grader	$1,200/actual mile
C. Perform no road preparation	-0-
IV. Mix Coherex® = and water in application truck	
A. Load Coherex®= into spray truck	
1. Pump Coherex® = from storage tank or drums into application truck	Tank--0 (included in price of storage tank) Drums--$1,000 capital
2. Pour Coherex® = from drums into application truck, using forklift	$1,000/treated mile

(continued)

TABLE B-14. (continued)

Program implementation alternatives	Cost
B. Load water into application truck	
1. Pump from river or lake	\$5,000 capital
2. Take from city water line	\$40/treated mile
V. Apply Coherex® = solution via surface spraying	
A. Use plant owned application truck	\$70,000 capital+\$135/treated mile for tank or \$270/treated mile for drums
B. Rent contractor application truck	Tank--\$500/treated mile Drums--\$1,000/treated mile

TABLE B-15. IDENTIFICATION AND COST ESTIMATION OF PETRO TAC CONTROL ALTERNATIVES

Program implementation alternatives	Cost
I. Purchase and ship Petro Tac	
A. Ship in truck tanker (4,000-6,000 gal/tanker)	$5,400/treated mile
B. Ship in drums via truck (55 gal/drum)	$11,500/treated mile
II. Store Petro Tac	
A. Store on plant property	
1. In new storage tank	$30,000 capital
2. In existing storage tank	
a. Needs refurbishing	$5,400 capital
b. Needs no refurbishing	-0-
3. In railcar tanker	
a. Own railcar	-0-
b. Pay demurrage	$20, $30, $60/treated mile
4. In truck tanker	
a. Own truck	-0-
b. Pay demurrage	$70/treated mile
5. In drums	-0-
B. Store in contractor tanks	$140/treated mile
III. Prepare road	
A. Use plant owned grader to minimize ruts and low spots	$630/actual mile
B. Rent contractor grader	$1,200/actual mile
C. Perform no road preparation	-0-
IV. Mix Petro Tac and water in application truck	
A. Load Petro Tac into spray truck	
1. Pump Petro Tac from storage tank or drums into application truck	Tank - 0 (included in price of storage tank) Drums--$1,000 capital
2. Pour Petro Tac from drums into application truck, generally using forklift	$1,000/treated mile
B. Load water into application truck	
1. Pump from river or lake	$5,000 capital
2. Take from city water line	$40/treated mile

(continued)

TABLE B-15. (continued)

Program implementation alternatives	Cost
V. Apply Petro Tac solution via surface spraying	
A. Use plant-owned application truck	$70,000 capital+$135/ treated mile for tank or $270/treated mile for drums
B. Rent contractor application truck	Tank--$500/treated mile Drums--$1,000/treated mile

APPENDIX C

SCREENING TECHNIQUES, MODELING INFORMATION, AND HEALTH RISKS INFORMATION

Page

Screening Analysis for Estimating Maximum Annual Average Ground-Level Particulate Matter Contaminant Concentrations... C-1

Estimating Health Effects From Fugitive Treatment, Storage, and Disposal Facilities (TSDF) Air Emissions................. C-19

Screening Analysis for Estimating Maximum Annual Average Ground-Level Particulate Matter Contaminant Concentrations

Introduction

The purpose of this section is to present a screening technique for estimating maximum annual average ground-level contaminant concentrations due to fugitive particulate matter emissions from treatment, storage, and disposal facilities (TSDFs).

The screening technique described in this section is a simplified procedure sufficiently conservative to allow a determination whether fugitive particulate matter emissions from a TSDF would: (1) clearly not result in an air quality threat or (2) pose a potential threat that should be examined with more sophisticated modeling techniques or measurements. If the screening estimates indicate that ground-level concentrations are not likely to exceed critical health risk levels, further analysis of the TSDF air quality impact is not necessary. If these screening estimates demonstrate that concentrations may exceed critical levels, this should not be construed as indicating a problem. Rather, it is an indication that more detailed source impact analyses using refined emissions estimates and air dispersion models are necessary.

The screening technique described in this section was developed expressly for TSDF guidance and should not be construed as EPA policy for any other source type. For each TSDF analysis, the State or U. S. Environmental Protection Agency (EPA) Regional Modeling contact should be consulted concerning the proper application of the screening technique and interpretation of results. The U. S. EPA Regional Modeling Contacts are identified in Table 1.

Table 1

Regional Meteorologists/Modeling Contacts

Susan Kulstad
EPA Region I
J.F.K. Federal Building
Boston, MA 02203-2211
(617) 565-3225

Ray Werner
EPA Region II
26 Federal Plaza
New York NY 10278
(212) 264-2517

Alan Cimorelli
EPA Region III
841 Chestnut Building
Philadelphia, PA 19107
(215) 597-6563

Lewis Nagler
EPA Region IV
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-2864

Michael Koerber
EPA Region V
230 South Dearborn Street
Chicago, IL 60604
(312) 886-6061

James Yarbrough
EPA Region VI
First Interstate Bank
Tower
1445 Ross Avenue
Dallas, TX 75202-2733
(214) 655-7214

Richard Daye
EPA Region VII
726 Minnesota Avenue
Kansas City, KS 66101
(913) 236-2896

John Notar
EPA Region VIII
999 18th Street
Denver Place - Suite 500
Denver, CO 80202-2405
(303) 293-1755

John Vimont
EPA Region IX
215 Fremont Street
San Francisco, CA 94105
(415) 974-8223

Robert Wilson
EPA Region X
Environmental Services
Division
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-1531

Limitations and Assumptions

This screening technique is designed to provide a simplified approach to obtain upper-bound concentration estimates for situations that may represent complex release scenarios and source configurations. Therefore, the screening methods have certain limitations such as the following:

* These methods assume that the particulate matter emissions behave as gaseous pollutants with negligible deposition velocities. Thus, these methods are not applicable for particulates with appreciable settling or when deposition is of concern.

* Steady, continuous emissions for the entire year are assumed.

* Complex and elevated terrain effects are not considered. However, for particulate matter plumes resulting from near ground-level, non-buoyant fugitive emission sources such as those at TSDFs, maximum ground-level concentrations are likely to occur at or near the property boundary. Thus, the assumption of flat terrain should have no effect on the magnitude of the maximum concentrations.

* The screening estimates presume that emissions are distributed evenly over a square area source representing a composite of all the fugitive particulate matter emission sources. This presumption may oversimplify a complex fugitive emissions source configuration.

The TSDF permit writer is strongly encouraged to discuss the appropriate application of this screening technique with the appropriate State and/or U. S. EPA Regional Modeling Contact.

Overview of Screening Procedures

Fugitive particulate matter emissions from TSDFs generally originate from surface areas such as the following:

* Roads (paved, unpaved)
* Open waste piles and staging areas
* Dry surface impoundments
* Landfills
* Land treatment
* Waste stabilization basins

Concentration estimates of contaminants contained in the fugitive particulate matter emissions are needed to estimate health risk to the surrounding populace. The purpose of a screening analysis is to provide permit writers an upper-bound estimate of contaminant concentration levels (based on fugitive particulate matter concentration levels) using simplified procedures.

The purpose of this screening analysis is to obtain an upper-bound estimate of the maximum annual average contaminant concentration resulting from fugitive particulate matter emissions from a TSDF. This screening analysis presumes that a total, combined annual emission rate is known for all applicable fugitive emission sources. Annual emission rates can be estimated using the procedures and emission factors detailed in this document. As noted above, the screening technique is based on the assumption of continuous emissions during the entire year.

Screening Analysis Methodology

This analysis utilizes Figure 1 which relates normalized annual average concentration estimates, CHI/Q (X/Q), to downwind distances for six generic area source sizes. The figure contains a "family-of-curves" - representing the six area source sizes - which plots normalized concentrations as a function of downwind distance.*

The X/Q plots shown in Figure 1 were developed by assuming unit emission rate per unit area per year (kg/m^2/yr) for each generic area source size. The procedures to obtain an upper-bound estimate of the maximum annual average concentration from a particular TSDF follow.

Step 1: Obtain an estimate of the total, combined fugitive particulate matter emission area source size. This size can be obtained by first estimating the total area containing each active source-type (e.g., the total area comprised of unpaved roads) and then summing the areas from each source-type to obtain a total combined area source size.

Step 2: Refer to Figure 1. From the total, combined area source size found in Step 1, determine the square area in Figure

---

* The curves were developed by applying the Industrial Source Complex (ISC) Long-Term Model based on the meteorological conditions representative of the general locations of the largest concentration of TSDF sources in the United States.[1]
Normalized concentration is defined as concentration divided by emission density or X/Q. Alternatively, the normalized concentration is the concentration that would be predicted if the emission density were 1 kg/m^2/yr.

X/Q VERSUS DISTANCE FOR SIX AREA SOURCE SIZES

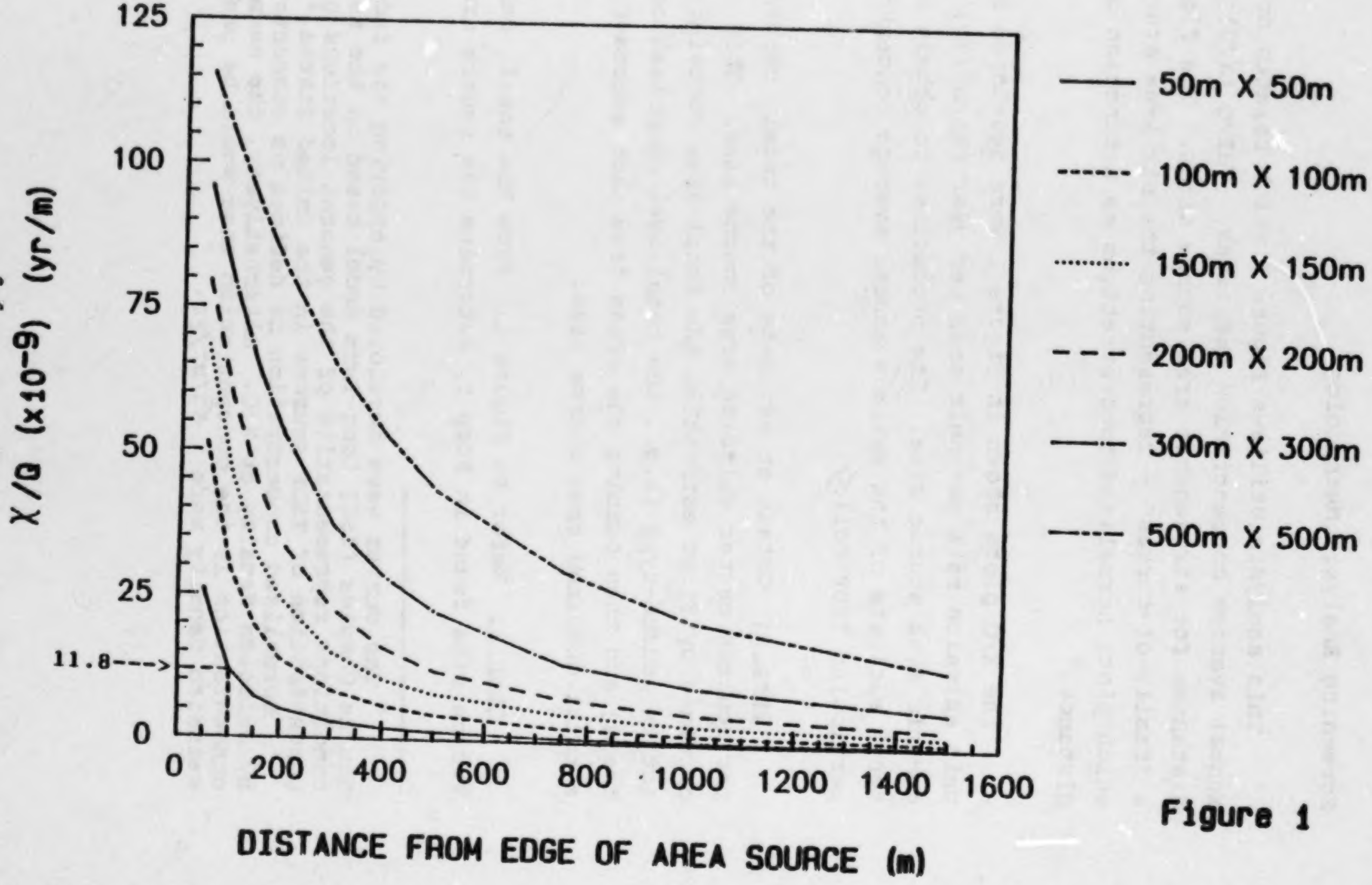

Figure 1

1 that best represents the combined area source size. For example, if the total combined area source size from Step 1 were approximately 10,000 square meters, the square area found in Figure 1 that would represent this source would be approximately 100 meters by 100 meters.

Step 3: Based on knowledge of the TSDF property lay-out (e.g., plot plan), estimate where the square area determined in Step 2 would be located within the property boundary in relation to the active sources used to determine the total combined area source size in Step 1.

Step 4: Determine the total annual contaminant emissions (kilograms) from all fugitive particulate matter emission sources that have been combined in this area source. Convert the total annual emissions to emissions (kilograms) per square meter using the area comprised of the square area source determined in Step 2.

Step 5: Refer to Figure 1. Locate the curve that best matches the square area source size determined in Step 2. Next, locate the distance to the nearest property boundary from the edge of the area source (Refer to Step 3). Locate the X/Q value for the appropriate downwind distance. Multiply the X/Q value by the fugitive particulate matter emissions per square meter determined in Step 4. The resulting concentration represents an upper-bound estimate of the maximum annual average contaminant concentration (ug/m^3) from the area source. This concentration is considered an upper-bound estimate because (1) emissions from all sources occur within the same area (i.e., are collocated), (2) emissions occur concurrently, (3) the annual X/Q values in Figure 1 represent the maximum values obtained from modeling a range of meteorological conditions associated with the locations of the largest TSDFs, and (4) the annual distribution of meteorological conditions is such that the maximum concentrations are assumed to occur in the direction of the nearest property boundary from the edge of the fugitive emissions area source.

Step 6: Compare the annual average contaminant concentration obtained in Step 5 with critical health risk levels. If this value exceeds the critical annual health risk threshold, more refined analyses are warrented. Otherwise, the TSDF facility may be assumed to pose minimal risk to the health threshold.

Example Problem: The following is an example of applying the screening procedure for a hypothetical TSDF. Consider the following hypothetical data:

Fugitive Source	Annual Contaminant Emission Rate (Kg)	Source Area (m^2)
Vehicular Traffic	0.90	400
Open Wastepiles	0.50	400
Dry Surface Impoundments	0.90	600
Landfills	0.10	300
Waste Stabilization Basin	0.40	500

Total annual contaminant emissions = 2.80 kg
Total fugitive emissions area source size = 2200 m^2
Thus Q = 2.80 kg/2200 m^2 = .00127 kg/m^2/yr
From Figure 1, the fugitive area source size is best represented

by the 50m X 50m ($2500m^2$) square area.

Distance from edge of square area source to nearest property boundary = 100 m.

Using Figure 1 as illustrated, X/Q = 11.8×10^{-9} yr/m

Therefore, upper-bound annual average concentration = (X/Q)(Q)

$$= (11.8 \times 10^{-9})(.00127)$$

$$= .015 \times 10^{-9} \text{ kg/m}^3 \text{ or } .015 \text{ ug/m}^3$$

Summary

The X/Q "family-of-curves" shown in Figure 1 were developed by applying the Industrial Source Complex (ISC) Long-Term Model for six generic area source sizes. It is possible that using other less rigorous screening techniques to estimate maximum annual average concentrations may in some cases yield more conservative results than those estimated from Figure 1. For example, the U. S. EPA's SCREEN Model[4] may be used to obtain short-term concentrations for area sources. These concentrations may then be multiplied by a scaling factor to obtain annual average concentrations. These annual average concentrations may be more conservative than those estimated from Figure 1 for some distances from the edge of the area source. However, at this time, there are no EPA-approved short-term to long-term scaling factors that may be used for area source screening.

Additionally, the "family-of-curves" shown in Figure 1 were developed for square area sources no greater than 500m X 500m. For larger area sources, it is recommended that the area source be represented by smaller area sources before screening techniques are applied. The State or U. S. EPA Regional Modeling Contact should be consulted for the proper techniques to be used in estimating annual average concentrations from area sources larger than 500m X 500m.

Detailed Facility Modeling Procedures

Introduction

The purpose of this section is to present an overview of detailed facility modeling procedures for estimating maximum annual average ground-level concentrations due to fugitive particulate matter emissions from treatment, storage, and disposal facilities (TSDFs)

If screening results indicate that annual average fugitive contaminant particulate matter concentrations may exceed critical levels, a more detailed modeling analysis of fugitive contaminent emissions from the TSDF is required. This detailed analysis is intended to predict maximum concentration levels from the fugitive particulate matter sources more accurately than the screening approach.

General guidance for conducting dispersion modeling is contained in U.S. EPA's Guideline on Air Quality Models (Revised).[2] This Guideline may be obtained from:

U. S. EPA
Source Receptor Analysis Branch
Techniques Evaluation Section
MD-14
Research Triangle Park, NC 27711
(919) 541-5685

or

National Technical
Information Service(NTIS)
U.S. Dept. of Commerce
Springfield, VA 22161
(703) 487-4650
NTIS No.: PB86-245248

This section describes a general approach for conducting a detailed modeling study of fugitive particulate matter emissions from a TSDF based upon information contained in the Guideline. Before proceeding with a detailed modeling study, the TSDF permit applicant should ensure that the appropriate U. S. EPA Modeling Contact (Table 1) is informed of all facets of the modeling protocol as it is developed. This is to ensure the proper consideration of the latest modeling techniques, procedures and requirements.

Model Selection

Fugitive particulate matter emissions from TSDFs are primarily generated from the following sources:

1. Roads (paved, unpaved)
2. Open waste piles and staging areas
3. Dry surface impoundments
4. Landfills
5. Land treatment
6. Waste stabilization basins

Because of the complexity in characterizing these emission sources, the most appropriate model to use for detailed modeling is the Industrial Source Complex (ISC) model.[2] Also, because long-term (i.e., annual average) concentrations are of concern, the ISC Long-Term (ISCLT) model is recommended for use in the detailed study.[2] The ISC model is available as part of the User's Network for Applied Modeling of Air Pollution (UNAMAP) (Version 6). The ISC user's guide[3] is available from:

Computer Products
National Technical Information Service (NTIS)
U.S. Department of Commerce
Springfield, VA 22161
(703) 487-4650
NTIS No.: PB88-169487

Additionally, the ISC model is available from various commercial vendors.

General Modeling Considerations

Receptor Sites

Receptor sites for the detailed facility modeling should be sufficient to estimate the highest annual average concentrations from the facility at locations to which the public has access. In designing a receptor network, receptor density and location is more important than the total number of receptors. The selection of receptor sites should be determined case-by-case considering the topography, climatology, monitoring sites and results of the initial screening. However, for near ground-level, non-buoyant TSDF fugitive particulate matter sources, the highest concentrations would likely be at or near the facility property boundary. Therefore, the greatest density of receptors should be at or near this boundary. Receptor and source locations are specified using a consistent set of polar or Cartesian coordinates. If polar coordinates are used, the origin is generally located at the facility's geographical centroid.

The State and U.S. EPA Regional Modeling Contacts should be consulted concerning the appropriate receptor selection prior to initiating the modeling study.

Gravitational Settling and Deposition

The ISC model contains settling and deposition algorithms that are recommended for use when the particulate matter size distribution can be quantified. Additional information concerning exercising gravitational settling and deposition algorithms in the ISC model is described below.

Urban/Rural Classification

The type of land use in which a TSDF is located is important to selecting the appropriate dispersion coefficients for use in the ISCLT model. The land use in the area of the TSDF must be classified as either urban or rural. The Guideline[2] details the procedures to use for determining the land use classification surrounding the TSDF.

TSDFs located in an area defined as urban should be modeled using urban dispersion coefficients, and TSDFs located in a rural area should use rural dispersion coefficients in the modeling.

ISCLT Program General Description

Cautionary note - because the proper application of many of the ISCLT model features requires a fundamental knowledge of the concepts of atmospheric transport and dispersion, the user should seek expert advice before using any ISCLT model feature not fully understood.

The ISCLT model uses statistical wind summaries to predict seasonal (i.e., quarterly) and/or annual ground-level concentrations at receptor sites specified using polar or Cartesian coordinates. Additionally, the model is designed to account for the effects of particulate gravitational settling and dry deposition on the predicted ambient concentrations. The annual concentration predictions are made for a finite number of wind-speed, wind-direction, and atmospheric turbulence combinations. The predicted concentrations are then weighted according to the observed frequency of occurrence of each combination.

The ISCLT model accepts the following source types: stack (e.g, point sources such as process vents), area and volume. For TSDF fugitive particulate matter emission sources, the source types would likely consist primarily of volume and area sources. The volume source option may be used to simulate line sources such as paved or unpaved roads. The area source option will likely be applied for sources such as landfills, dry surface impoundments, open waste piles, etc. The ISCLT user should seek expert advice on the proper configuration of the source types specific to the TSDF.

The ISCLT model has one rural and three urban modes for specifying the types of dispersion coefficients to use in the modeling. The selection of the proper option is dependent on the land use classification (rural or urban) in the vicinity of the TSDF. As described above, the Guideline[2] details the procedures to use for determining the land use classification. If the classification is urban, the Urban Mode 3 option should be selected in the ISCLT modeling.

Summary of ISCLT Input Data

The input requirements for the ISCLT program consist of four main categories:

* meteorological data
* source data
* receptor data
* program control parameters

Meteorological data

The ISCLT model utilizes meteorological data consisting of seasonal or annual statistical tabulations of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to Pasquill stability categories. These "STAR" summaries* are based on National Weather Service (NWS) hourly meteorological observations. The Guideline[2] provides additional specifications concerning the appropriate NWS data to use for the modeling of specific TSDFs. Typically, the nearest NWS station that best represents the meteorological conditions at the TSDF are used. The State or U.S. EPA Regional Modeling Contact should be consulted concerning the appropriate data to use.

Source Data

The ISCLT model accepts three source types: stack (or point sources such as process vents), area, and volume. For each source, input data requirements include the source location with respect to a user specified origin, the source elevation (if terrain effects are included in the model calculations) and annual average fugitive particulate matter emission rates. For stack or point-type sources (e.g., process vents) additional source input requirements include the physical stack height, inner stack diameter, stack gas exit temperature and stack exit velocity. Additionally, if the stack or point source is adjacent to a building and aerodynamic wake effects are a possibility, the length, width, and height of the building are needed as model input. The horizontal dimensions and effective emission height are required for each area and volume source. As noted above, it is anticipated that most sources within a TSDF may be characterized as area or volume sources.

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* The "STAR" summary is a tabulation of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to discrete atmospheric turbulence categories.

If gravitational settling and dry deposition are considered in the modeling, then source inputs must include (1) the mass fraction of particulates in discrete gravitational settling-velocity categories, and (2) the surface reflection coefficient and settling velocity of each settling-velocity category (see Reference 3, section 2.4.1, pg. 2-25). (For the modeling of PM_{10} fugitive particulate matter emissions, it may not be necessary to include gravitational settling and dry deposition in the ISCLT modeling).

Receptor Data

The ISCLT model uses either a polar (r, θ) or Cartesian (X,Y) coordinate system. The typical polar receptor array consists of radials (usually one for every 10 degrees azimuth) at several downwind distances. However, the user is not restricted to a 10-degree angular separation. For example, for the low-level sources associated with TSDF fugitive particulate matter emission sources, there may be a need to locate receptors closer than 10 degrees azimuth at the property boundary. The polar receptor array is always centered at X=0, Y=0, (usually at the facility's geographical centroid). Receptor locations in the Cartesian system may be input as Universal Tranverse Mercator (UTM) coordinates or as X (east-west) and Y (north-south) coordinates with respect to a user-specified origin.

Discrete receptor locations corresponding to other points of interest (e.g., population centroids) may be used with either coordinate system.

Program Control Parameters

The ISCLT model allows the user to select from a number of modeling options. Some of these options include:

* whether to specify concentration or deposition estimates at receptor locations,
* selection of polar versus Cartesian receptor grid system,
* specification of discrete receptor locations (e.g., population centroids, monitors),
* whether seasonal or annual output listings are desired,
* whether concentration calculations are based on rural or urban mode,
* output formats options,

The program control parameters for these and other options are discussed in detail in the ISC model user's guide[3] Section 4.2.3.

The TSDF permit applicant should consult with a modeling expert familiar with the ISCLT input and program control requirements prior to initiating a modeling analysis.

REFERENCES

1. Memorandum from D. Doll to L. Elmore documenting the ISCLT modeling analyses conducted to prepare Figure 1.

2. U.S. Environmental Protection Agency, Guideline on Air Quality Models (Revised) and Supplement A: EPA-450/2-78-027R, Office of Air Quality Planning and Standards, Research Triangle Park, NC, July 1986 and July 1987. Available from the National Technical Information Service (NTIS) as PB86-245248 and PB88-150958, respectively.

3. U.S. Environmental Protection Agency, Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition Volume 1 & 2: EPA-450/4-86-005a, Office of Air Quality Planning and Standards, Research Triangle Park, NC, June, 1986. Available from the National Technical Information Service as PB88-169487.

4. U.S. Environmental Protection Agency, Screening Procedures for Estimating the Air Quality Impact of Stationary Sources: EPA-450/4-88-010, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August, 1988. Available from the National Technical Information Service as PB89-159388.

ESTIMATING HEALTH EFFECTS FROM FUGITIVE TREATMENT, STORAGE, AND DISPOSAL FACILITIES (TSDF) AIR EMISSIONS

Many adverse health effects can result from exposure to fugitive air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF). The major pathways for human exposure to environmental contaminants are through inhalation, ingestion, or dermal contact. Airborne contaminants may be toxic to the sites of immediate exposure, such as the skin, eyes, and linings of the respiratory tract. Toxicants may also cause a spectrum of systemic effects following absorption and distribution to various target sites such as the liver, kidneys, and central nervous system. Generally, the health effects of greatest concern following intermittent or continuous long-term exposures are those that cause either irreversible damage and serious impairment to the normal functioning of the individual, such as cancer and organ dysfunctions, or death. Many toxicant effects can be reversible and disappear with cessation of exposure. Health effects sometimes associated with exposure to toxicants include: central nervous system effects such as headaches, drowsiness, and tremors; skin, eye, and respiratory tract irritation; nausea; reproductive and developmental effects; and olfactory effects such as awareness of unpleasant or disagreeable odors.

Exposure to contaminants in air can be acute, subchronic, or chronic. Acute exposure refers to a very short-term (i.e., ≤24 h), exposure to a contaminant. Acute exposure to very high concentrations or to low levels of highly toxic substances can cause serious and irreversible tissue damage, and even death. A delayed toxic response may also occur following acute exposure to certain agents. Chronic exposures are those that occur for long period of time (from many months to several years). Subchronic exposure falls between acute and chronic exposure, and usually involves exposure for a period of weeks or months.

The risk associated with exposure to a toxic agent is a function of many factors, including the physical and chemical characteristics of the substance, the nature of the toxic response and the dose required to produce the effect, the susceptibility of the exposed individual, and the exposure situation. In many cases individuals may be concurrently or sequentially exposed to a mixture of compounds, which may influence the risk by changing the nature and magnitude of the toxic response.

1. CANCER.

Calculation of cancer risk is based on the hypothesis that cancer rates in human populations are associated with individuals' exposure to pollutants present in the ambient air. In general, the scientific evidence that cancer risks may be associated with air pollution or specific pollutants in air is of three main types: epidemiologic studies of factors associated with cancer incidence; experimental or laboratory studies of the carcinogenicity and mutagenicity of substances and mixtures in the ambient air; and monitoring studies of the presence in the air of substances known to be carcinogenic.[1]

Cancer characteristically progresses through stages, each of which may be initiated or accelerated by a number of different intrinsic and extrinsic risk factors. Each factor may act at one or more stages, and different factors may interact in an additive or a synergistic way. Because of the long latency period between initial exposure and manifestation of many cancers (20 years or more), numerous opportunities exist for multiple exposures to potentially carcinogenic agents.[2]

a. Estimation of Cancer Potency

Two pieces of information are needed to assess the cancer risks of exposure to TSDF air emissions: (1) an estimate of the carcinogenic potency, or unit risk estimate, of the pollutants in TSDF air emissions; and (2) an estimate of the ambient concentration of the pollutants from TSDF that an individual or group of people breathe.

The unit risk estimate (unit risk factor) is used by the Environmental Protection Agency (EPA) in its analysis of carcinogens. It is defined as the lifetime cancer risk occurring in a hypothetical population in which all individuals are exposed throughout their lifetime (assumed to be 70 years) to an average concentration of 1 µg/m of the pollutant in the air they breathe. Unit risk estimates can be used for two purposes: (1) to compare the carcinogenic potency of several agents with one another, and (2) to give a rough indication of the public health risk that might be associated with estimated air exposure to these agents.[2]

Unit risk estimates for many of the TSDF pollutants covered in this report have been developed and reviewed by EPA. In the development of unit risk factors, EPA assumes that, if experimental data show that a substance is carcinogenic in animals, it may also be carcinogenic in humans. The EPA also assumes that humans may be as sensitive as the most sensitive animal species tested and that any exposure to a carcinogenic substance poses some risk.[2]

The EPA uses data from animal bioassay and epidemiologic studies to predict risk to humans at low exposure to the substance. Both the animal and human studies usually reflect populations exposed to relatively high levels of a given substance; however, general population exposure to the substance is usually low. Because the risks at low-level exposure cannot be measured directly by animal or epidemiologic studies, a number of mathematical models have been developed to extrapolate low-dose risk from the high-dose studies. There is no single model which is most appropriate for identifying "true" risk estimates. EPA (1986) noted that in assessments conducted by the Agency, "in the absence of adequate information to the contrary, the linearized multistage model will be employed." This model has been used for many, but not all, of the TSDF chemicals. For more details of the quantitative assessments the reader is referred to the Integrated Risk Information System (IRIS)at 513-569-7254. The Agency has chosen to use nonthreshold models for dose-response assessment. The basis for nonthreshold models is primarily theoretical based on how background incidence and heterogenicity in the population effect the shape of population dose-response curves. [For more information on this issue the reader is referred to Hoel et al., 1975[3]; Schneiderman et al., 1979[4]; EPA, 1984[5]; and Gaylor 1988[6] .

The unit risk values predicted from human data are generally maximum likelihood or "best estimates" of risk. The unit risk values predicted from animal data provide a plausible, upper bound limit on public risk at lower exposure levels if the exposure is accurately quantified; i.e., the true risk is unlikely to be higher than the calculated level and could be substantially lower.

For animal data, the mathematical formulation chosen to describe the linear nonthreshold dose-response relationship at low doses is applied to original unadjusted animal data. Risk estimates produced by this model from the animal data are then scaled to a human equivalent estimate of risk. This is done by multiplying the estimates by several factors to adjust for experiment duration, species differences, and, if necessary, route conversion. The conversion factor for species differences is presently based on models for equitoxic dose.[7] The method that has been used in most of the EPA's quantitative risk assessments assumes dose equivalence in units of mg/body weight 2/3 for equal tumor response in rats and humans. It is assumed that metabolic rate is roughly proportional to body surface areas and that surface area is proportional to 2/3 power of body weight (as would be the case for a perfect sphere). The estimate is also adjusted for lifetime exposure to the carcinogen considering duration of exposure (either occupational exposure duration or duration of the experiment) and animal lifetime.[2]

For unit risk estimates for air, studies using exposure by inhalation are preferred. When extrapolating results from the inhalation studies from animals to humans, consideration is given to the following factors:

- The deposition of the inhaled compound throughout the respiratory trace
- Retention half-time of the inhaled particles
- Metabolism of the inhaled compound
- Differences in sites of tumor induction.

Unit risk estimation from human or animal studies is only an approximate indication of the actual risk in populations exposed to known concentrations of a carcinogen. Differences between species (life span, body size, metabolism, immunological responses, target site susceptibility), as well as differences within species (genetic variation, disease state, diet), can cause actual risk to be much different. In human populations, variations also occur in genetic constitution, diet, living environment, and activity patterns. Some populations may demonstrate a higher susceptibility due to certain metabolic or inherent differences in their response to the effects of carcinogens. Also, unit risk estimates are based on exposure to a referent adult male. Exposed individuals are represented by a referent male having a standard weight, breathing rate, etc. (No reference is made to factors such as race or state of health.) There may be an increased risk with exposure by fetuses, children, or young adults. Finally, humans are exposed to a variety of compounds, and the health effects, either synergistic or antagonistic, of exposure to complex mixtures of chemicals are not known.[2,7]

b. EPA Unit Risk Estimates

The EPA has developed unit risk estimates (URE) for about 72 compounds that are either known or suspect carcinogens and that could be present at a TSDF. The EPA has verified about 35 of these. As shown in Table 1, these URE range in value from 5.8 x 10^{-7} $(\mu g/m^3)^{-1}$ for perchloroethylene to 3.3 x 10^{-5} $(pg/m^3)^{-1}$ for dioxin. In other words, the URS for perchloroethylene is 5.8 cancer cases per every 10 million people exposed to 1 $\mu g/m^3$ perchloroethylene. The URE for dioxin is 3.3 cancer cases per every 100 people exposed to 1 $\mu g/m^3$ dioxin. The URE for a given chemical is multiplied by the estimate of exposure to produce a risk estimate. For example, if exposure to perchloroethylene was estimated to be 10 $\mu g/m^3$ the risk would be

$$10\ \mu g/m^3 - 5.8 \times 10^{-7}/\mu g/m^3 = 5.8 \times 10^{-6}$$

(or 5.8 cancer cases for every one million people exposed to 10 $\mu g/m^3$ perchloroethylene). The URE are revised upon occasion, therefore the user is advised to confirm that the values are the most correct for the compounds of concern. To verify, call the IRIS coordinator at 513-569-7254.

c. Noncancer Health Effects

Although cancer is of great concern as an adverse health effect associated with exposure to a chemical or a mixture of chemicals, many other health effects may be associated with such exposures. These effects may range from subtle biochemical, physiological, or pathological effects to gross effects such as death. The effects of greatest concern are the ones that are irreversible and impair the normal functioning of the individual. Some of these effects include respiratory toxicity, developmental and reproductive toxicity, central nervous system effects, and other systemic effects such as liver and kidney toxicity, cardiovascular toxicity, and immunotoxicity.

d. Health Benchmark Levels

For chemicals that give rise to toxic endpoints other than cancer and gene mutations, there is often assumed to be a level of exposure below which adverse health effects usually do not occur. This threshold-of-effect assumption maintains that an organism can tolerate a range of exposures from zero to some finite value without risk of experiencing a toxic effect. Above this threshold, toxicity is observed as the organism's homeostatic, compensating, and adaptive mechanisms are overcome. To provide protection against adverse health effects in even the most sensitive individuals in a population, regulatory efforts are generally made to prevent exposures from exceeding a health "benchmark" level that is hypothetically below the lowest of the thresholds of the individuals within a population.

Benchmark levels, termed reference doses (RfD), are operationally derived from an experimentally obtained no-observed-effect level or a lowest-observed-effect level by consistent application of generally order-of-magnitude uncertainty factors. The uncertainty factors reflect various types of data used to estimate RfD. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of daily exposure to the human population (including sensitive subpopulations) that is likely to be without an appreciable risk of deleterious effect. These benchmark levels are compared to exposure to qualitatively evaluate risk. The greater the exceedance of the RfD the greater the risk.

The Agency has developed verified oral RfD for a large number of chemicals, but has only recently established a working group to begin the process for inhalation RfD. In the absence of such inhalation values, the noncancer health effects assessment utilizes an interim approach for deriving chronic exposure limits that is similar to that used in the Agency's proposed rule on the burning of hazardous waste in boilers and industrial furnaces (52 FR 16982). These interim values will be used until such time as Agency-verified inhalation RfD become available.

The Agency is using the following strategy to derive the interim inhalation benchmark levels:

(1) Where a verified oral RfD has been based on an inhalation study, the inhalation exposure limit will be calculated directly from the study.

(2) Where a verified oral RfD has been based on an oral study, the inhalation exposure limit will be calculated by converting the daily human oral dose to a corresponding concentration in air. Route extrapolation will only be performed after careful evaluation of the confounding factors affecting the conversion. Some of these factors include: (a) occurrence of critical toxicological effects at the portal of entry, (b) differences in systemic effects, (c) first pass effects resulting in inactivation or activation of the chemical before it reaches the target organ, (d) effect of route upon dosimetry, and (e) variations in temporal patterns of target organ concentrations.[8]

(3) Where there exist appropriate EPA health documents containing relevant inhalation toxicity data, those data will be used in deriving an inhalation exposure limit. Such documents include Health Assessment Documents, Health Effects Assessments, and Health Effects and Environmental Profiles. Other health documents (e.g., National Institute of Occupational Safety and Health criteria documents) or sources of toxicity information (e.g., data used to support the development of the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value) will also be considered. The calculation of an interim inhalation health benchmark level will be made in accordance with the Agency's RfD Methodology.

The methodology for converting oral RfDs to interim inhalation benchmark levels is as follows:

Benchmark level (mg/m^3) =

$$\frac{\text{RfD(mg/kg-bw/day)} \times \text{Body weight} \times \text{Correction factor}}{\text{m}^3 \text{ Air breathed/day}}$$

where

- RfD is the oral reference dose
- Body weight is assumed to be 70 kg for an adult male
- Correction factor for route-to-route extrapolation (going from the oral route to the inhalation route) is 1.0, unless specific data exist that indicate a more appropriate value
- Volume of air breathed by an adult male is assumed to be 20 m^3/day.

Until Agency verified inhalation RfD become available, alternatives measures might be used. These alternatives might include each State's own reference doses, that are usually derived from Threshold Limit Values. The Agency's RfDs can be obtained from the Integrated Risk Information System (IRIS). The IRIS user support can be accessed by calling 513-569-7254.

e. Chemicals of Concern

A preliminary list of 179 TSDF chemicals of concern for the noncancer health assessment is shown in Table 2 along with the available interim health benchmark levels. Constituents were drawn from the Agency's final rule on the identification and listing of hazardous waste (Appendix VIII of Reference 9) and from several hazardous waste data bases identified by the Research Triangle Institute.[10] To be selected from these sources, the chemical must have had either an Agency-verified oral reference dose (as of September 30, 1987)[8] or a Reference

Air Concentration (RAC) found in the Agency's proposed rule on the burning of hazardous waste in boilers and industrial furnaces.[12] Additional chemicals were added to Table 2 based on knowledge of a high toxicity associated with that substance.

2. RISK ASSESSMENT

a. Maximum Lifetime Risk

Maximum lifetime risk or individual risk refers to the person or persons estimated to live in the area of highest ambient air concentrations of the pollutant(s) as determined by the detailed facility modeling. This individual is assumed to reside at the plant fenceline. The maximum lifetime risk reflects the probability of an individual developing cancer as a result of continuous exposure to the estimated maximum ambient air concentration for 70 years. The use of the work "maximum" in maximum lifetime risk does not mean the greatest possible risk of cancer to the public. It is based only on the maximum exposure estimated by the procedure used [10], and it does not incorporate uncertainties in the exposure estimate or the risk factor.

Maximum lifetime risk is calculated by multiplying the highest annual average concentration at the fenceline by the unit risk estimate. The product is the probability of developing cancer for those individuals assumed to be exposed to this concentration for their lifetimes. The following example problem utilizes the upper-bound annual average concentration for chromium that was determined in the example problem discussed in the "Screening Techniques for Estimating Maximum Annual Average

Ground-Level Concentrations Due to Fugitive Particulate Emissions from TSDF" located in this appendix. The unit risk estimate for chromium was obtained from Table 1 and is $0.012/\mu g/m^3$.

$$\text{Maximum lifetime risk} = (\text{highest annual avg. conc.})\ (\text{unit risk estimate})$$

$$= (15.0\ \mu g/m^3)\ (0.012/\mu g/m^3)$$

$$= 1.8 \times 10^{-1}$$

Thus, anyone residing at this average concentration for 70 years would have about a 2 in 10 chance of developing the cancer of concern.

b. Noncancer Health Effects

(1) Chronic Exposures

The assessment of noncancer health effects associated with chronic exposures to TSDF chemicals of concern is based on a comparison of the chemical-specific health benchmark levels (as discussed in Section 1.d to estimated ambient concentrations at various receptor locations around a facility. Inhalation exposure limit will be compared to the highest annual average ambient concentrations for each chemical at the selected facilities. These annual concentrations represent an estimation of the highest average daily ambient concentration experienced over a year. Ambient concentrations that are less than the RfD are not likely to be associated with health risks. The probability that adverse effects may be observed in a human population will increase as the frequency of exposures exceeding the RfD increases and as the size of the excess increases. The results of this assessment will be available after completion of an ongoing scientific review of the inhalation benchmark levels discussed in Section 1.d.

(2) Acute Exposures

Assessment of the potential for noncancer health effects associated with short-term (acute) exposure to TSDF chemicals of concern at selected facilities will be conducted as a screening effort to provide additional qualitative support to the overall noncancer health effects analysis. The extent of this assessment will be limited by the lack of short-term exposure limits and by the lack of adequate acute inhalation data for most of the TSDF chemicals of concern. The assessment will be conducted by comparing maximum modeled ambient concentrations for averaging times of 15 minutes, 1 hour, 8 hours, and 24 hours to available short-term health data matched to the appropriate averaging time. These data will be obtained from various sources, including EPA reports an documents, data used to support occupational exposure recommendations and standards (e.g., ACGIH Documentation of TLVs), and other published information. Determination of the risk of adverse health effects associated with estimated short-term exposures will be based on a consideration of the quality of the available health data and the proximity of the exposure concentration to the health effect level. This phase of the noncancer health effects assessment is incomplete at this time.

3. ANALYTICAL UNCERTAINTIES APPLICABLE TO CALCULATIONS OF PUBLIC HEALTH RISKS IN THIS APPENDIX

a. Unit Risk Estimate

The procedure generally used to develop unit risk estimates is fully described in Reference 2. Nickel was selected as an example. The model used and its application to epidemiological and animal data have been the subjects of substantial comment by health scientists. The uncertainties are too complex to be summarized sensibly in this appendix. Readers who wish to go beyond the information presented in the reference should see the following FEDERAL REGISTER notices: (1) EPA's "Guidelines for Carcinogenic Risk Assessment," 51 FR 33972 (September 24, 1986[2]), and (2) EPA's "Chemical Carcinogens; A Review of the Science and its Associated Principles," 50 FR 10372 (March 14, 1985), February 1985.

Other significant uncertainties associated with the cancer unit risk factors include: (1) selection of dose/response model, (2) selection of study used to estimate the unit risk estimate, and (3) presence or absence of a threshold.

b. Ambient Air Concentrations

The following are relevant to the estimated ambient air concentrations used in this analysis:

- Flat terrain was assumed in the dispersion model. Concentrations much higher than those estimated would result if emissions impact on elevated terrain or tall building near a plant.

- The estimated concentrations do not account for the additive impact of emissions from plants located close to one another.
- The increase in concentrations that could result from reentrainment of pollutant-bearing dust from, for example, city streets, dirt roads, and vacant lots, is not directly considered.
- With few exceptions, the emission rates are based on assumptions and on limited emission tests.

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10. Memorandum from Coy, Dave, RTI, to McDonald, Randy, EPA/OAQPS. May 2, 1986. Listing of waste constituents prioritized by quantity.

11. U.S. Environmental Protection Agency. Status Report of the RfD Work Group. Environmental Criteria and Assessment Office, Cincinnati, OH. 1987.

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TABLE 1. TSDF CARCINOGEN LIST

	Constituent	Unit risk estimate ($\mu g/m^3$)$^{-1}$	Basis[a]
1.	acetaldehyde (75-07-0)	2.2×10^{-6}	CAG UCR (class B2)
2.	acrylamide (79-06-1)	1.1×10^{-4}	CAG UCR (class B2)
3.	acrylonitrile (107-13-1)	6.8×10^{-5}	CRAVE verified UCR (class B1)
4.	aldrin (309-00-2)	4.9×10^{-3}	CRAVE verified UCR (class B2)
5.	aniline (62-53-3)	7.4×10^{-6}	CAG UCR (class C)
6.	arsenic (7440-38-2)	4.3×10^{-3}	CAG UCR (class A)
7.	benz(a)anthracene (56-55-3)	8.9×10^{-4}	CAG UCR (class B2)
8.	benzene (71-43-2)	8.0×10^{-6}	CAG UCR (class A)
9.	benzidine (92-87-5)	6.7×10^{-2}	CRAVE verified UCR (class A)
10.	benzo(a)pyrene (50-32-8)	1.7×10^{-3}	CAG UCR (class B2)
11.	beryllium (7440-41-7)	2.4×10^{-3}	CAG UCR (class B2)
12.	bis(chloroethyl) ether (111-44-4)	3.3×10^{-4}	CRAVE verified UCR (class B2)
13.	bis(chloromethyl ether (542-88-1)	2.7×10^{-3}	CAG UCR (class A)
14.	1,3-butadiene (106-99-0)	2.8×10^{-4}	CRAVE verified UCR (class B2)
15.	cadmium (7440-43-9)	1.8×10^{-3}	CRAVE verified UCR (class B1)

(continued)

TABLE 1 (continued)

	Constituent	Unit risk estimate, $(\mu g/m^3)^{-1}$	Basis[a]
16.	carbon tetrachloride (56-23-5)	1.5×10^{-5}	CRAVE verified UCR (class B2)
17.	chlordane (12789-03-6)	3.7×10^{-4}	CRAVE verified UCR (class B2)
18.	chloroform (67-66-3)	2.3×10^{-5}	CAG UCR (class B2)
19.	chloromethane (74-87-3)	3.6×10^{-6}	ECAO UCR (class C)
20.	chloromethyl methyl ether (107-30-2)	2.7×10^{-3}	CAG UCR (class A)
21.	chromium VI (7440-47-3)	1.2×10^{-2}	CRAVE verified UCR (class A)
22.	DDT (50-29-3)	3.0×10^{-3}	CAG UCR (class B2)
23.	dibenz(a,h) anthracene (53-70-3)	1.4×10^{-2}	CAG UCR (class B2)
24.	1,2-dibromo-3-chloropropane (96-12-8)	6.3×10^{-3}	CAG UCR (class B2)
25.	1,2-dichloroethane (107-06-2)	2.6×10^{-5}	CRAVE verified UCR (class B2)
26.	1,1-dichloroethylene (75-35-4)	5.0×10^{-5}	CRAVE verified UCR (class C)
27.	dieldrin (60-57-1)	4.6×10^{-3}	CRAVE verified UCR (class B2)
28.	diethylstilbestrol (56-53-1)	1.4×10^{-1}	CAG UCR (class A)
29.	2,4-dinitrotoluene (121-14-2)	8.8×10^{-5}	CAG UCR (class B2)

(continued)

TABLE 1 (continued)

Constituent	Unit risk estimate, $(\mu g/m^3)^{-1}$	Basis[a]
30. 1,4-dioxane (123-91-1)	1.4×10^{-6}	CAG UCR (class B2)
31. 1,2-diphenylhydrazine (122-66-7)	2.2×10^{-4}	CRAVE verified (class B2)
32. epichlorohydrin (106-89-8)	1.2×10^{-6}	CRAVE verified UCR (class B2)
33. ethylene dibromide (106-93-4)	2.2×10^{-4}	CRAVE verified UCR (class B2)
34. ethylene oxide (75-21-8)	1.0×10^{-4}	CAG UCR (class B1-B2)
35. formaldehyde (50-00-0)	1.3×10^{-5}	CAG UCR (class B1)
36. gasoline (8006-61-9)	6.6×10^{-7}	CAG UCR (class B2)
37. heptachlor (76-44-8)	1.3×10^{-3}	CRAVE verified UCR (class B2)
38. heptachlor epoxide (1024-57-3)	2.6×10^{-3}	CRAVE verified UCR (class B2)
39. hexachlorobenzene (118-74-1)	4.9×10^{-4}	CAG UCR (class B2)
40. hexachlorobutadiene (87-68-3)	2.2×10^{-5}	CRAVE verified UCR (class C)
41. hexachlorocyclohexane (no CAS #)	5.4×10^{-4}	CRAVE verified UCR (class B2)
42. alpha-hexachlorocyclohexane (319-84-6)	1.8×10^{-3}	CRAVE verified UCR (class B2)
43. beta-hexachlorocyclohexane (319-85-7)	5.3×10^{-4}	CRAVE verified UCR (class B2)

(continued)

TABLE 1 (continued)

Constituent	Unit risk estimate $(\mu g/m^3)^{-1}$	Basis[a]
44. gamma-hexachlorocyclohexane (lindane)(58-89-9)	3.8×10^{-4}	CRAVE verified UCR (class C)
45. hexachlorodibenzo-p-dioxin,1:2 mixture (57653-85-7 or 19408-74-3)	1.3×10^{-6}	CRAVE verified UCR (class B2)
46. hexachloroethane (67-72-1)	4.0×10^{-6}	CRAVE verified UCR (class C)
47. hydrazine (302-01-2)	2.9×10^{-3}	CAG UCR (class B2)
48. 3-methylcholanthrene (56-49-5)	2.7×10^{-3}	CAG UCR (class B2)
49. 4,4'-methylene-bis (2-chloroaniline) (101-14-4)	4.7×10^{-5}	CAG UCR (class B2)
50. methylene chloride (75-09-2)	4.7×10^{-7}	CAG UCR UCR (class B2)
51. methyl hydrazine (60-34-4)	3.1×10^{-4}	ECAO UCR (class B2)
52. nickel refinery dust (7440-02-0)	2.4×10^{-4}	CRAVE verified UCR (class A)
53. nickel subsulfide (12035-72-2)	4.8×10^{-4}	CRAVE verified UCR (class B2)
54. 2-nitropropane (79-46-9)	2.7×10^{-3}	CAG UCR (class B2)
55. n-nitrosodi-n-butylamine (924-16-3)	1.6×10^{-3}	CRAVE verified UCR (class B2)
56. n-nitrosodiethylamine (55-18-5)	4.3×10^{-2}	CRAVE verified UCR (class B2)

(continued)

TABLE 1 (continued)

	Constituent	Unit risk estimate ($\mu g/m^3$)$^{-1}$	Basis[a]
57.	n-nitrosodimethylamine (62-75-9)	1.4×10^{-2}	CRAVE verified UCR (class B2)
58.	n-nitroso-n-methylurea (684-93-5)	8.6×10^{-2}	CAG UCR (class B2)
59.	n-nitrosopyrrolidine (930-55-2)	6.1×10^{-4}	CRAVE verified UCR (class B2)
60.	polychlorinated biphenyls (1336-36-3)	1.2×10^{-3}	CAG UCR (class B2)
61.	pentachloronitrobenzene (82-68-8)	7.3×10^{-5}	CAG UCR (class C)
62.	pronamide (23950-58-5)	4.6×10^{-6}	CAG UCR (class C)
63.	reserpine (50-55-5)	3.0×10^{-3}	CAG UCR (class B2)
64.	2,3,7,8-tetrachlorodibenzo-p-dioxin (1746-01-6)	3.3×10^{1}	CAG UCR (class B2)
65.	1,1,2,2-tetrachloroethane (79-34-5)	5.8×10^{-5}	CRAVE verified UCR (class C)
66.	tetrachloroethylene (127-18-4)	5.8×10^{-7}	CRAVE verified UCR (class C)
67.	thiourea (62-56-6)	5.5×10^{-4}	CAG UCR (class B2)
68.	toxaphene (8001-35-2)	3.2×10^{-3}	CRAVE verified UCR (class B2)

(continued)

TABLE 1 (continued)

	Constituent	Unit risk estimate $(\mu g/m^3)^{-1}$	Basis[a]
69.	1,1,2-trichloroethane (79-00-5)	1.6×10^{-5}	CRAVE verified UCR (class C)
70.	trichloroethylene (79-01-6)	1.7×10^{-6}	CAG UCR (class B2)
71.	2,4,6-trichlorophenol (88-06-2)	5.7×10^{-6}	CRAVE verified UCR (class B2)
72.	vinyl chloride (75-01-4)	4.1×10^{-6}	CAG UCR (class A)

[a] The inhalation exposure limits are derived from unit cancer risk (UCR) estimates, which were either (1) verified by the Carcinogen Risk Assessment Verification Exercise (CRAVE) work group or (2) established by the Carcinogen Assessment Group (CAG), but not yet verified by CRAVE. The unit risk estimates for chloromethane and methyl hydrazine were derived by the Environmental Criteria and Assessment Office (ECAO).

Note: The constituents on this list and the corresponding unit risk estimates and exposure limits are subject to change.

TABLE 2 TSDF CHEMICALS - NONCANCER HEALTH EFFECTS ASSESSMENT

Chemical	Interim health benchmark level ($\mu g/m^3$)[a]	Chemical	Interim health benchmark level ($\mu g/m^3$)[a]
acetone (67-64-1)	--	bromoform (75-25-2)	--
acetaldehyde[b,c] (75-07-0)	--	butanol (71-36-3)	--
acetonitrile (75-05-8)	40	cadmium[b,c] (7440-43-9)	--
acetophenone[b] (98-86-2)	2,000	calcium chromate[b,c] (13765-19-0)	--
acetyl chloride[b] (75-36-5)	20	calcium cyanide (592-01-8)	100
1-acetyl-2-thiourea[b] (591-08-2)	--	carbon disulfide (75-15-0)	800
acrolein[c] (107-02-8)	40	carbon oxyfluoride[b] (353-50-4)	--
acrylic acid (79-10-7)	--	carbon tetrachloride[c] (56-23-5)	--
acrylonitrile[b,c] (107-13-1)	--	chlordane[c] (12789-03-6)	--
aldicarb (116-06-3)	--	chlorine[b] (7782-50-5)	--
aldrin[c] (309-00-2)	--	chloroacetaldehyde[b] (107-20-0)	--
allyl alcohol (107-18-6)	--	2-chloro-1,3-butadiene[b] (126-99-8)	10
allyl chloride[b,c] (107-05-1)	--		
aluminum phosphide (20859-73-8)	1	chloroform[b] (67-66-3)	--
5-aminomethyl-3-isoxazolol[b] (2763-96-4)	--	chloromethane[b,c] (74-87-3)	--
		3-chloropropionitrile[b] (542-76-7)	--
4-aminopyridine[b] (504-24-5)	--	chromium III (7440-47-3)	4,000
ammonia[b] (7664-41-7)	--	chromium VI (7440-47-3)	--
ammonium vanadate[b] (7803-55-6)	--	copper cyanide[b] (544-92-3)	200
antimony (7440-36-0)	1	cresols[c] (1319-77-3)	400
arsenic[b,c] (7440-38-2)	--	crotonaldehyde[b] (4170-30-3)	--
barium (7440-39-3)	200	cumene (98-82-8)	--
barium cyanide (542-62-1)	200	cyanide (57-12-5)	60
benzidine[c] (92-87-5)	--	cyanogen (460-19-5)	100
benzoic acid (65-85-0)	--	cyanogen bromide[b] (506-68-3)	--
berylium[c] (7440-41-7)	--	cyanogen chloride (506-77-4)	--
1,1-biphenyl (92-52-4)	--	cyclohexanone (108-94-1)	--
bis(2-ethylhexyl)phthalate[c] (117-81-7)	60	2,4 D (dichlorophenoxyacetic acid) (94-75-7)	--
bromodichloromethane (75-27-4)	--	DDT[c] (50-29-3)	--

(continued)

TABLE 2 (continued)

Chemical	Interim health benchmark level ($\mu g/m^3$)^{b}
decabromodiphenyl oxide (1163-19-5)	--
di-n-butyl phthalate (84-74-2)	400
1,2-dichlorobenzene^{b} (95-50-1)	40
1,4-dichlorobenzene^{b,c} (106-46-7)	40
dichlorodifluoromethane (75-71-8)	600
1,1-dichloroethane^{b,c} (75-34-3)	200
1,1-dichloroethylene^{b,c} (75-35-4)	--
2,4-dichlorophenol (120-83-2)	10
1,3-dichloropropene^{c} (542-75-6)	1
dieldrin^{c} (60-57-1)	--
diethyl phthalate (84-66-2)	40,000
dimethoate (60-51-5)	4
dimethyl amine^{b} (124-40-3)	--
dimethyl aniline (121-69-7)	--
(alpha, alpha) dimethyl phenethylamine^{b} (122-09-8)	--
dimethylterephthalate (120-61-6)	--
2,4-dinitrophenol (51-28-5)	4
dinoseb (88-85-7)	--
diphenyl amine (122-39-4)	900
disulfoton (298-04-4)	--
endosulfan (115-29-7)	0.04
endothall (129-67-9)	--
endrin^{b} (72-20-8)	0.2
epichlorohydrin^{c} (chloro-2,3-epoxy-propane) (106-89-8)	--
ethyl acetate (141-78-6)	--
ethyl benzene (100-41-4)	--
ethylene glycol (107-21-1)	--
ethylene oxide^{b,c} (75-21-8)	--

Chemical	Interim health benchmark level ($\mu g/m^3$)^{c}
ethylene thiourea^{c} (96-45-7)	--
fluoracetic acid, sodium salt^{b} (62-74-8)	--
fluoride (16984-48-8)	--
fluorine^{b} (7782-41-4)	200
formaldehyde^{b,c} (50-00-0)	--
formic acid (64-18-6)	6,000
freon 113 (76-13-1)	--
furan (110-00-9)	--
gamma-hexachlorocyclohexane^{b} (lindane) (58-89-9)	--
heptachlor^{c} (76-44-8)	3.4
heptachlor epoxide^{c} (1024-57-3)	--
hexachlorobutadiene^{c} (87-68-3)	--
hexachlorocyclopentadiene (77-47-4)	20
hexachloroethane^{c} (67-72-1)	--
hydrogen chloride^{b} (7647-01-0)	60
hydrogen cyanide (74-90-8)	60
hydrogen sulfide (7783-06-4)	10
isobutyl alcohol (78-83-1)	1,000
lead^{b} (7439-92-1)	0.30
maleic hydrazide^{c} (123-33-1)	--
malonitrile^{b} (109-77-3)	--
mercury (7439-97-6)	60
methacrylonitrile^{b} (126-98-7)	--
methomyl (16752-77-5)	92
methoxyclor^{b} (72-43-5)	200
methyl bromide (bromomethane) (74-83-9)	20

(continued)

TABLE 2 (continued)

Chemical	Interim health benchmark level ($\mu g/m^3$)^b	Chemical	Interim health benchmark level ($\mu g/m^3$)^c
methyl chloroform (1,1,1-trichloroethane) (71-55-6)	--	2-propyn-1-ol^b (107-19-7)	--
methylene chloride^c (75-09-2)	--	pyridine (110-86-1)	20
methyl ethyl ketone (78-93-3)	300	selenious acid (selenium dioxide) (7783-00-8)	10
methyl iodide^{b,c} (74-88-4)	--	selenourea (630-10-4)	20
methyl iosbutyl ketone (108-10-1)	--	silver (7440-22-4)	20
methyl isocyanate^b (624-83-9)	--	silver cyanide (506-64-9)	400
2-methyl lactonitrile^b (75-86-5)	31	silvex (93-72-1)	--
methyl parathion (298-00-0)	10	sodium azide (26628-22-8)	--
nickel carbonyl^{b,c} (13463-39-3)	--	sodium cyanide (143-33-9)	--
nickel cyanide^b (557-19-7)	60	styrene^c (100-42-5)	--
nickel refinery dust^c (7440-02-2)	--	strychnine (57-24-9)	1
nitric oxide (10102-43-9)	100	1,2,4,5-tetrachlorobenzene (95-94-3)	1
nitrobenzene^c (98-95-3)	2	1,1,1,2-tetrachloroethane^c (630-20-6)	--
4-nitroquinoline-1-oxide^b (56-57-5)	--	tetrachloroethylene^c (127-18-4)	--
osmium tetroxide^b (20816-12-0)	--	2,3,4,6-tetrachlorophenol (58-90-2)	40
pentachlorobenzene^{b,c} (608-93-5)	4	tetraethyl dithiopyrophosphate^b (3689-24-5)	--
pentachloroethane^{b,c} (76-01-7)	--	tetraethyl lead (78-00-2)	4×10^{-4}
pentachloronitrobenzene (82-68-8)	--	thallic oxide (1314-32-5)	1
pentachlorophenol (87-86-5)	100	thallium^b (7440-28-0)	2,000
phenol (108-95-2)	400	thallium (1) ucetate (563-68-8)	2
m-phenylenediamine^b (25265-76-3)	20	thallium (1) carbonate (6533-73-9)	1
phenylmercuric acetate (62-38-4)	0.32	thallium (1) chloride (7791-12-0)	2
phosgene^b (75-44-5)	--	thallium (1) nitrate (10102-45-1)	2
phosphine (7803-51-2)	1	thallium (1) selenite (12039-52-0)	2
potassium cyanide (151-50-8)	200	thallium (1) sulfate^b (10031-59-1)	2
potassium silver cyanide (506-61-6)	600	thiomethanol (methyl mercaptan)^b (74-93-1)	--
pronamide^c (23950-58-5)	--	thiosemicarbazide^b (79-19-6)	--
propanenitrile^b (107-12-0)	--		
n-propylamine^b (107-10-8)	--		

(continued)

TABLE 2 (continued)

Chemical	Interim health benchmark level (µg/m^3)[a]	Chemical	Interim health benchmark level (µg/m^3)[a]
thiram (137-26-8)	--	1,2,3-trichloropropane (96-18-4)	--
toluene (108-88-3)	2,000	vanadium pentoxide (1314-62-1)	80
1,2,4-trichlorobenzene (120-82-1)	80	warfarin (81-81-2)	--
1,1,2-trichloroethane[b] (79-00-5)	--	xylene(s) (1330-20-7)	--
trichloromonofluoromethane (75-69-4)	1,000	zinc cyanide (557-21-1)	--
		zinc phosphide (12037-79-5)	--
2,4,5-trichlorophenol[c] (95-95-4)	400	zineb[c] (12122-67-7)	

[a] Interim health benchmark levels are unapportioned and thus are four times the value of the reference air concentrations in the preamble correction to the proposed rule on burning of hazardous waste in boilers and industrial furnaces (52 FR 25612).

[b] No RFD.

[c] Carcinogen.

Note: The constituents on this list and the interim health benchmark levels are subject to change.

APPENDIX D

SAMPLING AND ANALYSIS PROCEDURES

SECTION 1

INTRODUCTION

As indicated throughout the preceding text, for a given facility the most reliable estimates of contaminated particulate emissions are obtained using site-specific information as developed through a well-designed S&A program. This appendix outlines procedures and general information to be used in developing an S&A program. The appendix borrows extensively from information contained in References 1 and 2.

The overall goal of the S&A program is to collect and analyze (for physical and chemical properties) "representative" samples of the soil and surface material at TSDFs. The information generated from the exercise, in turn, feeds directly into the emission factor models discussed in the main text. The sampling parameters of concern include the following:

- Silt content
- Silt loading (for paved surfaces)
- Moisture content
- (α) level of contamination

One of the most critical decisions required in development of the S&A plan involves specification of a sampling design. In practice, sampling designs can be divided into two broad categories--those that are statistical or probability based, and those that are based on professional judgment. Whenever possible, statistically based schemes are preferred as resulting data often can be reduced to provide measures of sampling and analysis reliability. Probably the most widely applied statistical schemes are: (1) simple random and (2) systematic random sampling. Both of these schemes proceed with reference to a sample grid like that shown in Figure 1-1. Under the simple random design, a predetermined number (n) of individual samples are collected, one from each of n randomly selected grid cells. Under the systematic design, the initial sampling grid cell is randomly selected; subsequent samples are then collected at a regular interval (e.g., every other grid cell) in one or more directions from the starting point. Detailed discussions of statistical sampling designs can be found in References 3 and 4.

Implicit in the use of statistically based schemes is a substantial commitment of resources for both sampling and laboratory analyses. If resources are very limited, it may be desirable to use judgment sampling to produce initial data for emissions estimates. In essence, judgment sampling implies that the person responsible for collection can choose sampling location(s) that are broadly representative of the source in question.

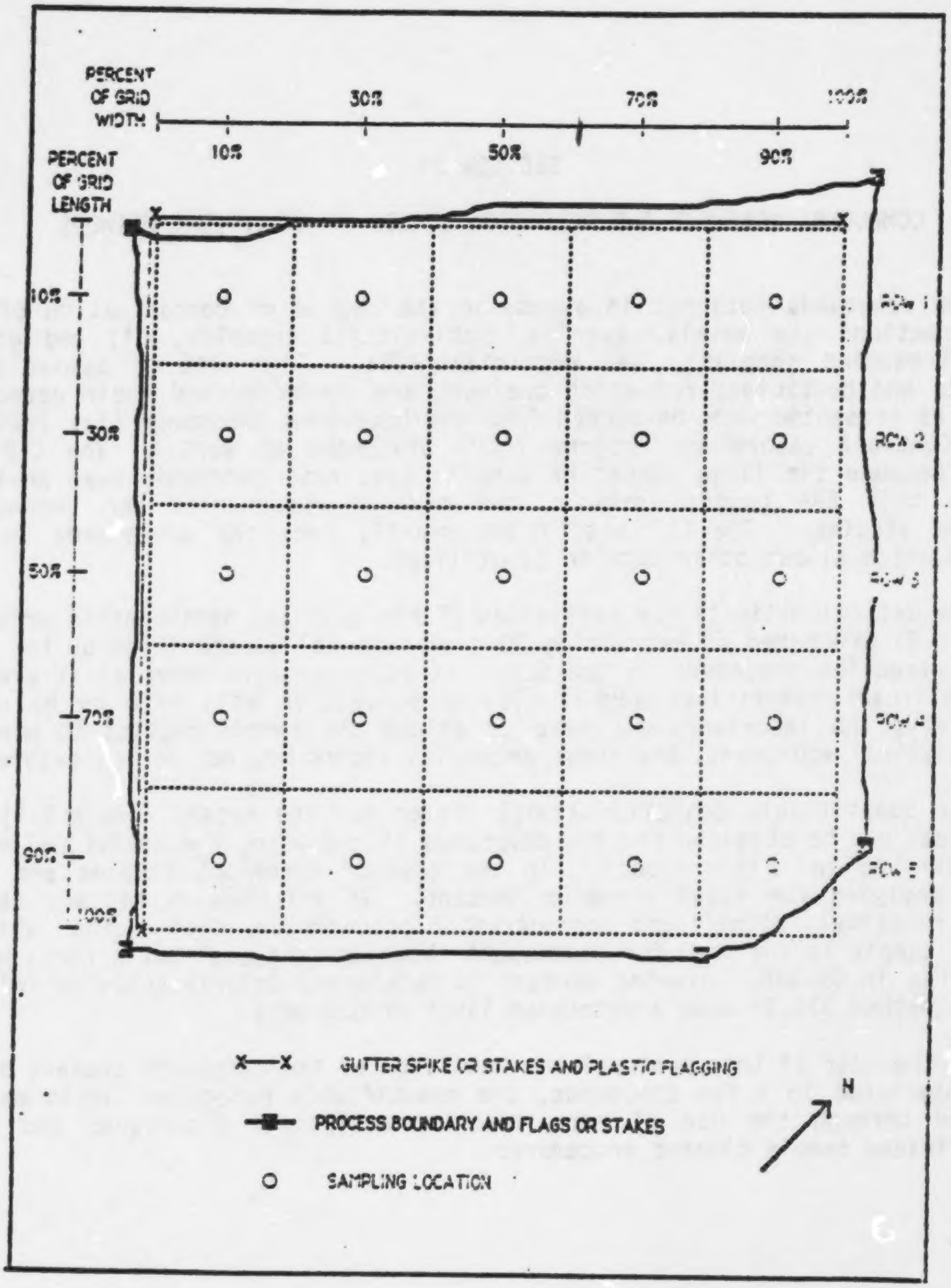
PERCENT OF GRID WIDTH
10%
30%
50%
70%
90%
100%
PERCENT OF GRID LENGTH
10%
30%
50%
70%
90%
100%
ROW 1
ROW 2
ROW 3
ROW 4
ROW 5
X—X GUTTER SPIKE OR STAKES AND PLASTIC FLAGGING
PROCESS BOUNDARY AND FLAGS OR STAKES
SAMPLING LOCATION
N

Figure 1-1. Sample grid for hypothetical TSDF source.

SECTION 2*

COMPOUNDS MEASURED AND DETECTION LIMITS OF ANALYTICAL METHODS

The compounds measured in assessing the degree of contamination of the soil fractions are metals, cyanide, semivolatile organics, oil and grease (land treatment samples), and pesticides/PCBs. The list of semivolatile organics and pesticides for which analyses are conducted and their detection limits as presented were developed from the Hazardous Substance List (HSL) in EPA's Contract Laboratory Program (CLP) Statement of Work.[5] The CLP was chosen because the large number of samples that have currently been analyzed through this EPA program provide the maximum opportunity for technology transfer studies. The CLP also draws heavily from the procedures in EPA SW-846[6] which allows other data to be utilized.

The detection limits for pesticides (Table 2-1) and semivolatile organics (Table 2-2) are based on extracting 30 g of material as specified by the low-level extraction procedure in the CLP. If other organic material is present in significant quantities, sample cleanup procedures will have to be used. Ultimately, the laboratory may have to dilute the sample extract to protect the analytical equipment, and these detection limits may not be achievable.

The quantifiable detection limits listed for the metals (Table 2-3) are those that can be obtained for the compounds listed using the analytical methods described in this protocol. In the case of chromium, samples are initially analyzed for total chromium content. If the results for any sample show a relatively significant concentration of chromium, then another aliquot of that sample is analyzed for hexavalent chromium (the most toxic form) using procedures in SW-846. Cyanide content is determined colorimetrically following EPA Method 335.2[6] with a detection limit of 0.5 µg/g.

If the user of this protocol has knowledge of the compounds present or is only interested in a few compounds, the quantifiable detection limits may be improved through the use of more specific analytical techniques and more sophisticated sample cleanup procedures.

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* The material in this section is taken directly from Reference 2.

TABLE 2-1. PESTICIDE DETECTION LIMITS

1	ALDRIN	8
2	Alpha - BHC	8
3	Beta - BHC	8
4	Delta - BHC	8
5	Gamma - BHC	8
6	CHLORDANE	80
7	4,4'-DDD	16
8	4,4'-DDE	16
9	4,4'-DDT	16
10	DIELDRIN	16
11	ENDOSULFAN I	8
12	ENDOSULFAN II	16
13	ENDOSULFAN SULFATE	16
14	ENDRIN	16
15	ENDRIN KETONE	16
16	HEPTACHLOR	8
17	HEPTACHLOR EPOXIDE	8
18	TOXAPHENE	160
19	AROCLOR 1016	80
20	AROCLOR 1221	80
21	AROCLOR 1232	80
22	AROCLOR 1242	80
23	AROCLOR 1248	80
24	AROCLOR 1254	160
25	AROCLOR 1260	160

TABLE 2-2. SEMIVOLATILE ORGANIC DETECTION LIMITS

Number	Compounds	Detection (ug/kg)
1	ACENAPHTHENE	330
2	ACENAPHTHYLENE	330
3	ANTHRACENE	330
4	BENZO (a) ANTHRACENE	330
5	BENZOIC ACID	1600
6	BENZO (a) PYRENE	330
7	BENZO (ghi) PERYLENE	330
8	BENZO (b) FLUORANTHENE	330
9	BENZO (k) FLUORANTHENE	330
10	BENZYL ALCOHOL	330
11	BIS (2-CHLOROETHOXY) METHANE	330
12	BIS (2-CHLOROETHYL) ETHER	330
13	BIS (2-CHLOROISOPROPYL) ETHER	330
14	BIS (2-ETHYHEXYL) PHTHALATE	330
15	4-BROMOPHENYL PHENYL ETHER	330
16	BUTYL BENZYL PHTHALATE	330
17	4-CHLOROANILINE	330
18	4-CHLORO-3-METHYLPHENOL	330
19	2-CHLORONAPHTHALENE	330
20	2-CHLOROPHENOL	330
21	4-CHLOROPHENYL PHENYL ETHER	330
22	CHRYSENE	330
23	DIBENZO (a.h) ANTHRACENE	330
24	DIBENZOFURAN	330
25	1.2 DICHLOROBENZENE	330
26	1.3 DICHLOROBENZENE	330
27	1.4 DICHLOROBENZENE	330
28	3.3'-DICHLOROBENZIDINE	330
29	2.4-DICHLOROPHENOL	330
30	DIETHYLPHTHALATE	330
31	2.4-DIMETHYLPHENOL	330
32	DIMETHYL PHTHALATE	330
33	DI-N-BUTYLPHTHALATE	330
34	2.4-DINITROPHENOL	1600
35	2.4-DINITROTOLUENE	330
36	2.6-DINITROTOLUENE	330
37	DI-N-OCTYL PHTHALATE	330
38	FLUORANTHENE	330
39	FLUORENE	330
40	HEXACHLOROBENZENE	330
41	HEXACHLOROBUTADIENE	330
42	HEXACHLOROCYCLOPENTADIENE	330
43	HEXACHLOROETHANE	330
44	INDENO(1.2.3-cd) PYRENE	330
45	ISOPHORONE	330
46	2-METHYL-4.6-DINITROPHENOL	330
47	2-METHYLNAPHTHALENE	330
48	2-METHYLPHENOL	330
49	4-METHYLPHENOL	330
50	NAPHTHALENE	330
51	2-NITROANILINE	1600
52	3-NITROANILINE	1600
53	4-NITROANILINE	1600
54	NITROBENZENE	330
55	2-NITROPHENOL	330
56	4-NITROPHENOL	1600
57	N-NITROSO-DI-N-PROPYLAMINE	330
58	N-NITROSODIPHENYLAMINE	330
59	PENTACHLOROPHENOL	1600
60	PHENANTHRENE	330
61	PHENOL	330
62	PYRENE	330
63	1.2.4-TRICHLOROBENZENE	330
64	2.4.5-TRICHLOROPHENOL	1600
65	2.4.6-TRICHLOROPHENOL	330

TABLE 2-3. METALS, MEASUREMENT METHODS, AND QUANTIFIABLE DETECTION LIMITS

Number	Element	Measurement Method**	Quantifiable Detection Limits (µg/g)
1	Aluminum (Al)	ICAP	40
2	Antimony (Sb)	GFAA	1.0
3	Arsenic* (As)	GFAA	1.0
4	Barium* (Ba)	ICAP	0.7
5	Beryllium (Be)	ICAP	0.1
6	Bismuth (Bi)	ICAP	10.0
7	Cadmium* (Cd)	ICAP	0.4
8	Chromium* (Cr)	ICAP+	0.7
9	Cobalt (Co)	ICAP	0.7
10	Copper (Cu)	ICAP	7.3
11	Iron (Fe)	ICAP	100
12	Lead* (Pb)	ICAP	10.0
13	Manganese (Mn)	ICAP	5.9
14	Mercury* (Hg)	Cold Vapor AA	0.25
15	Molybdenum (Mo)	ICAP	9.0
16	Nickel (Ni)	ICAP	2.2
17	Osmium (Os)	ICAP	4.0
18	Selenium* (Se)	GFAA	1.0
19	Silver* (Ag)	ICAP	10
20	Thallium (Tl)	GFAA	1.0
21	Vanadium (V)	ICAP	3.9
22	Zinc (Zn)	ICAP	0.2

*Eight RCRA metals

**ICAP = Inductively-Coupled Argon Plasmography

GFAA = Graphite Furnace Atomic Absorption

AA = Atomic Absorption

+Other methods are used to measure hexavalent chromium (Cr IV), if appropriate (see page E-4).

SECTION 3

FIELD SAMPLING PROCEDURES

3.1 SAMPLING METHODS

The procedures for sampling the soil/surface material at HW TSDFs can be divided into four basic types--sweeping, scooping, coring, and vacuuming.

Sweeping refers to the use of a whisk broom and dust pan to remove loose surface material from the underlying hard packed surface. The material should be swept carefully so that the fine dust is not injected into the atmosphere. The hard road base below the loose surface material should not be abraded so as to generate more fine material than exists on the road in its natural state.

Scooping refers to the use of a small garden spade or comparable implement to obtain samples of near surface material from a potential dust emitting source. Note that Reference 2 calls for the use of small disposable scoops that may be appropriate depending upon the nature of the material being sampled.

Coring refers to the use of a simple coring tube to extract samples to nominal depths of 15 cm (6 in). Two types of coring tubes are employed: one made of stainless steel (to collect samples for organic analyses) and one made of PVC plastic (to collect samples for metals analyses). The procedure involves driving the core tube into the surface (with a mallet or other compatible tool), extracting the core tube from the soil, and forcing the soil core into the sample container by pushing a wooden dowel through the tube.

Vacuuming refers to the use of a common household vacuum cleaner to remove surface material from a paved roadway. Note that the vacuum bag should use removable, disposable paper bags.

In the following table the sampling procedures are cross-referenced against potentially applicable source categories.

Source Category	Sampling Procedure
Paved roads	Vacuuming
Unpaved roads	Broom sweeping
Waste piles	Scooping, coring
Dry surface impoundments	Sweeping[a]
Landfills	Scooping, sweeping
Land treatment	Coring, scooping
Stabilization/solidification	Scooping, coring

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[a] Assumes wind erosion is the only particulate generating mechanism.

3.2 UNPAVED ROADS

For unpaved roads, MRI typically has recommended collection of a minimum gross sample of 23 kg (50 lb) for every 3.8 km (3 mi) of unpaved road. The incremental samples from unpaved roads should be distributed over the road segment as shown in Figure 3-1. At least four incremental samples should be collected and composited to form the gross sample. Figure 3-2 presents a data form to be used for the sampling of unpaved roads.

3.3 PAVED ROADS

In industrial facilities, like HW TSDFs, MRI typically has recommended that one gross sample should be obtained for each road segment in the facility. The gross sample should consist of at least two separate increments per travel lane, or each 0.5 mi length should have a separate sample.

Figure 3-3 presents a diagram showing the location of incremental samples for a four-lane road. Each incremental sample should consist of a lateral strip 0.3 to 3 m (1 to 10 ft) in width across a travel lane. The exact width is dependent on the amount of loose surface material on the paved roadway. For a visually dirty road, a width of 0.3 m (1 ft) is sufficient; but for a visually clean road, a width of 3 m (10 ft) is needed to obtain an adequate sample.

The above sampling procedure may be considered as the preferred method of collecting surface dust from paved roadways. In many instances, however, the collection of eight sample increments may not be feasible due to manpower, equipment, and traffic/hazard limitations. As an alternative method, samples can be obtained from a single strip across all the travel lanes. When it is necessary to resort to this sampling strategy, care must be taken to select sits that have dust loading and traffic characteristics typical of the entire roadway segment of interest. In this situation, sampling from a strip 3 to 9 m (10 to 30 ft) in width is suggested. From this width, sufficient sample can be collected, and a step toward representativeness in sample acquisition will be accomplished.

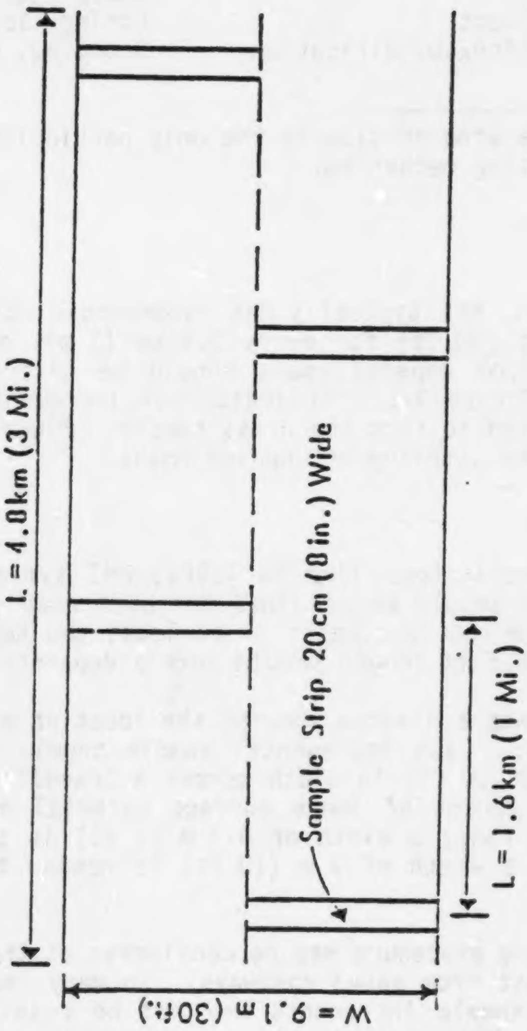
L = 4.8km (3 Mi.)
Sample Strip 20cm (8 in.) Wide
L = 1.6km (1 Mi.)
W = 9.1 m (30ft.)

Figure 3-1. Location of incremental sampling sites on an unpaved road.

Sample No.	Time	Location*	Surface Area	Depth	Quantity of Sample

*Use code given on plant map for segment identification and indicate sample location on map.

Figure 3-2. Sampling data form for unpaved roads.

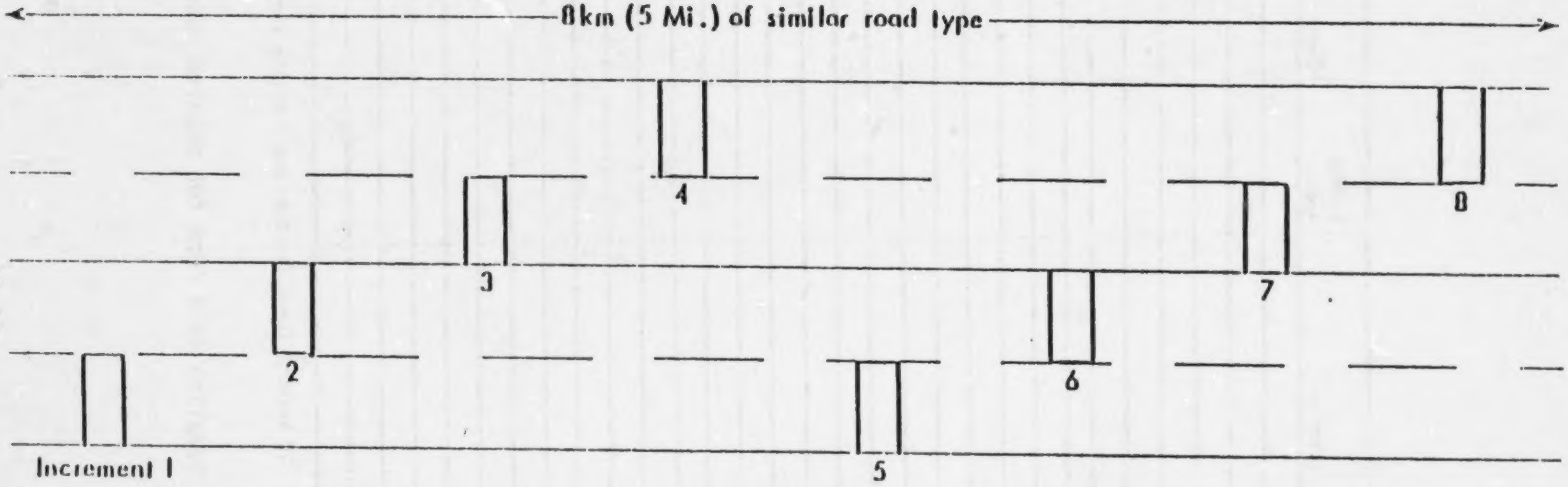
8km (5 Mi.) of similar road type
Increment 1
2
3
4
5
6
7
8

Figure 3-3. Location of incremental sampling sites on a paved road.

Samples are removed from the road surface by vacuuming, preceded by broom sweeping if large aggregate is present. The samples should be taken from the traveled portion of the lane with the area measured and recorded on the appropriate data form. With a whisk broom and a dust pan, the larger particles are collected from the sampling area and placed in a clean, labeled container (plastic jar or bag). The remaining smaller particles are then swept from the road with an electric broom-type vacuum sweeper. The sweeper must be equipped with a preweighed, prelabeled, disposable vacuum bag. Care must be taken when installing the bags in the sweeper to avoid torn bags which can result in loss of sample. After the sample has been collected, the bag should be removed from the sweeper, checked for leaks and stored in a prelabeled, gummed envelope for transport. Figure 3-4 presents a data form to be used for the sampling of paved roads.

Values for the dust loading on only the traveled portion of the roadway are needed for inclusion in the appropriate emission factor equation. Information pertaining to dust loading on curb/beam and parking areas is necessary in estimating carry-on potential to determine the appropriate industrial road augmentation factor.

3.3 LANDFILLS, LAND TREATMENT UNITS, DRY SURFACE IMPOUNDMENTS

Reference 2 provides a detailed sampling protocol that is potentially applicable to landfills, land treatment units, and dry surface impoundments. This sampling approach is outlined below; note that the discussion can be referenced to Figure 3-5.

__________________________*

For the systematic grid sampling, a 5 x 5 rectangular grid matrix is used. This grid is superimposed over the process area. Sample aliquots are then collected from the process by sampling the center of each of the 25 grid cells.

To locate the sampling grid on the process, a rough sketch of the process can be made (see example in Figure 3-5). A form such as that shown in Figure 3-6 may be used to sketch the process and sampling grid in the field. Considering the shape and dimensions of the process, the grid should be superimposed over the process so that:

- The maximum area of the process (at least 85% by visual approximation) is inside the grid.
- No more than 25% (by visual approximation) of the grid area is outside the process boundaries.

Once they are determined, Figure 3-6 may be used to record the grid dimensions and orientation.

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* Material taken directly from Reference 2.

Type of Material Sampled: ______________________

Site of Sampling: __________ No. of Traffic Lanes __________

Type of Pavement: Asphalt/Concrete __________ Surface Condition __________

Sample No.	Vac. Bag	Time	Location*	Sample Area	Broom Swept? (y/n)

*Use code given on plant map for segment identification and indicate sample location on map.

Figure 3-4. Sampling data form for paved roads.

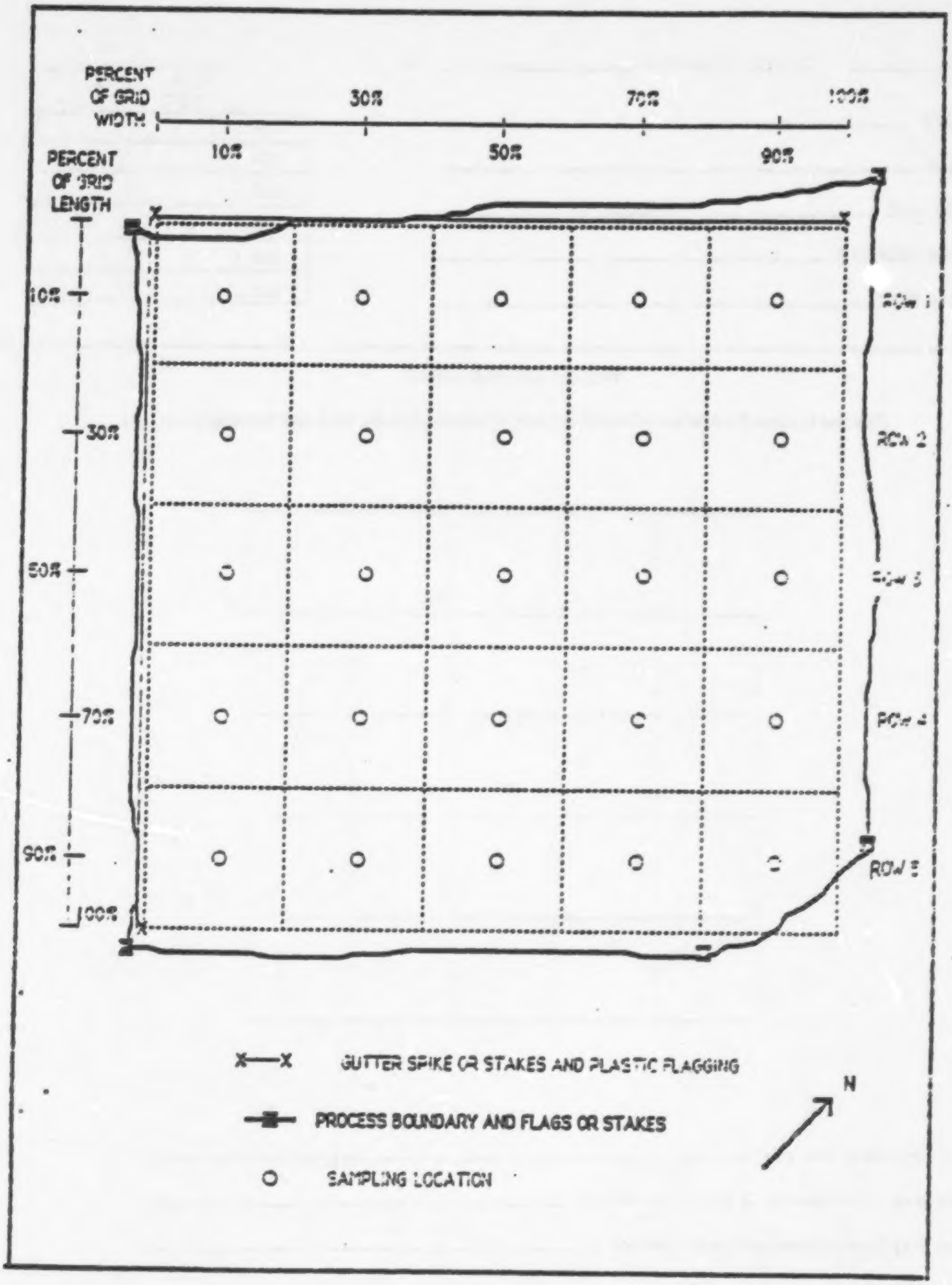
PERCENT OF GRID WIDTH
10%
30%
50%
70%
90%
100%
PERCENT OF GRID LENGTH
10%
30%
50%
70%
90%
100%
ROW 1
ROW 2
ROW 3
ROW 4
ROW 5
X—X GUTTER SPIKE OR STAKES AND PLASTIC FLAGGING
PROCESS BOUNDARY AND FLAGS OR STAKES
○ SAMPLING LOCATION
N

Figure 3-5. Sample grid for hypothetical TSDF source.

DATE ________ PROCESS DESIGNATION ____________________

SITE NAME ____________________

LOCATION ____________________

PROCESS NAME ____________________

SAMPLING TECHNIQUE ____________________

SAMPLING TEAM ____________________

	GRID LENGTH	GRID WIDTH
100%		
10%		
30%		
50%		
70%		
90%		

PROCESS AND GRID LAYOUT

(Indicate Process Boundaries & Dimensions, Grid Dimension & Orientation, and Sampling Locations.)

Total Area inside Grid (LxW) ____________________

Total Area of Processes Inside Grid (include Names) ____________________

Total Area Covered Inside Grid (Note Covering) ____________________

Total Effective Process Area Inside Grid ____________________

Figure 3-6. Example form for sketching process and grid specifications and recording sampling information.

The following technique is recommended for marking the sampling grid on the process itself. First, drive wooden stakes or gutter spikes into the ground at three of the grid corners. Then, run lengths of plastic flagging between the stakes or spikes to define two perpendicular sides of the grid. The table in Figure 3-6 may be used to calculate the distances along the grid length and width used to locate the sampling points.

For example, to locate the points on the first row of the grid, mark a point along the flagging at 10% of the grid length. A test team member located at that point can then feed the appropriate length of surveyor's tape or chain to another test team member as he moves across the grid parallel to the grid width which has been marked with plastic flagging. The sampling points will be at 10%, 30%, 50%, 70%, and 90% of the grid width. As these points are located they should be staked or flagged.

Carefully document the relationship of the grid to process boundaries and other landscape features. This includes estimating the square area of those areas within the grid that are permanently covered preventing wind erosion. These areas include standing water, rock piles, gravel, drums, etc. The sum of these areas must be subtracted from the total area of the grid (length x width) which will be used in modeling the fugitive particulate emissions. Areas of other processes not being examined may fall within the grid area such as the active face of a landfill in a landfill area, or an access road or equipment access area; these areas must also be subtracted from the grid area.

In some cases, there may be some obstacle to sampling at the center of a grid cell. These obstacles may include: (1) standing water, (2) waste drums or other waste containers, (3) parked equipment, (4) rocks, and (5) significant holes at the location. Under these circumstances, the sample should be taken at another suitable point in the cell as close to the center as possible. If an entire cell is covered by one or more of these obstacles, then that cell is not sampled and as previously stated, all the area covered is subtracted from the total area of the grid.

Some process configurations and/or relationships to other processes may increase the difficulty in choosing a rational grid location. One such situation is illustrated in Figure 3-7. In this case, the grid is located to maximize process coverage. It covers a portion of another process (the access road) and a portion of a pond. Two of the grid cells are not sampled at all since their entire area covers a separate process and/or an area of permanent coverage (the standing water in the pond). As previously discussed, the permanently covered area within the grid (the pond) must be subtracted from the total area of the grid and the area of the access road (a separate process) within the grid must also be subtracted. If these grid cells instead covered nonprocess related land that was not permanently covered, then it would be appropriate to sample them (see the next example).

In another case illustrated in Figure 3-8 (1) a separate process (active face of a landfill) falls in the middle of the process being sampled (the landfill) and (2) one entire grid cell falls outside the process. In this case, all the grid cells are sampled (see Figure 3-8 for locations). The grid is superimposed over the process so that the active face will not completely

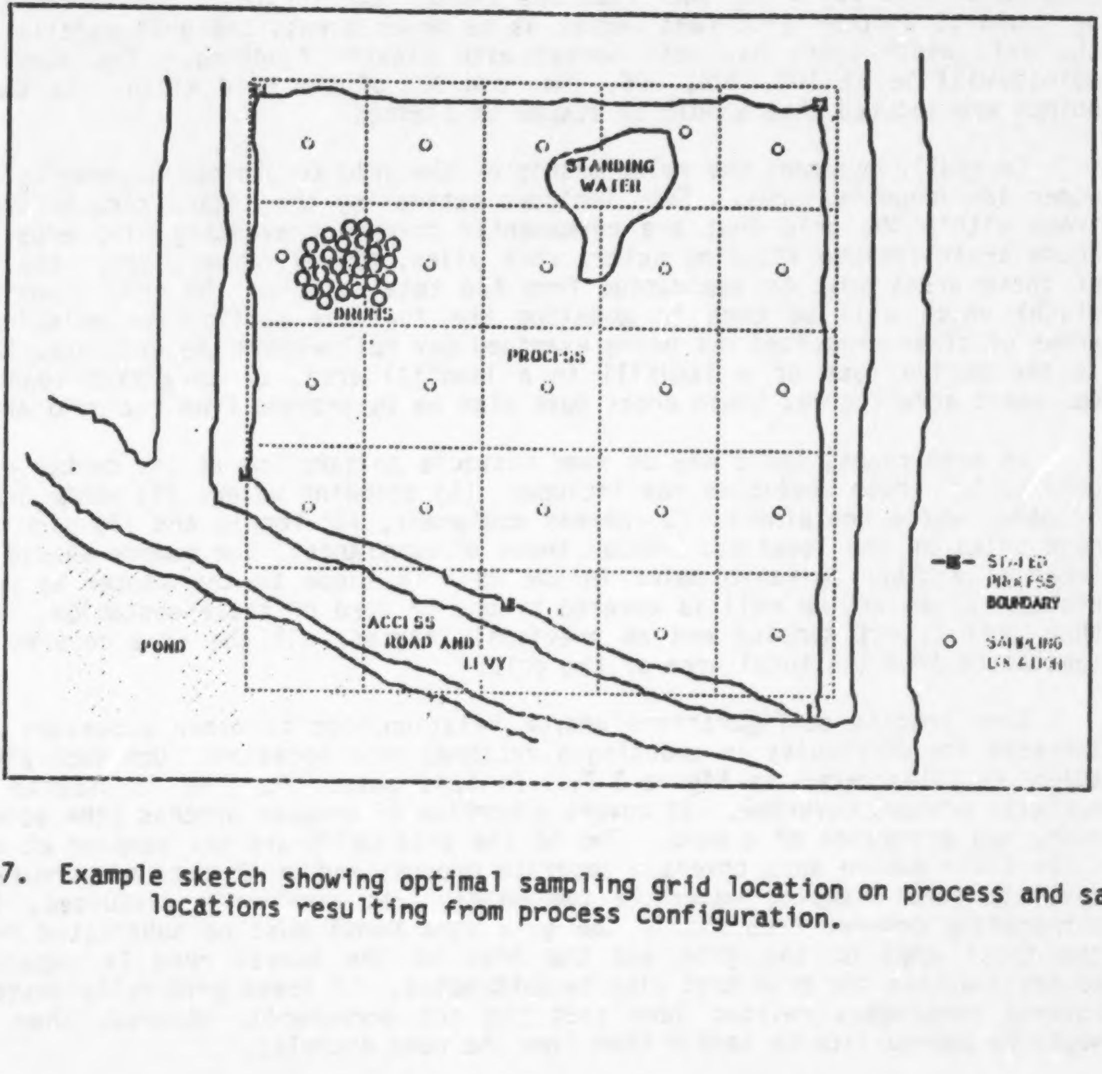
STANDING WATER
DRUMS
PROCESS
ACCESS ROAD AND LEVY
POND
STATED PROCESS BOUNDARY
SAMPLING LOCATION

Figure 3-7. Example sketch showing optimal sampling grid location on process and sampling locations resulting from process configuration.

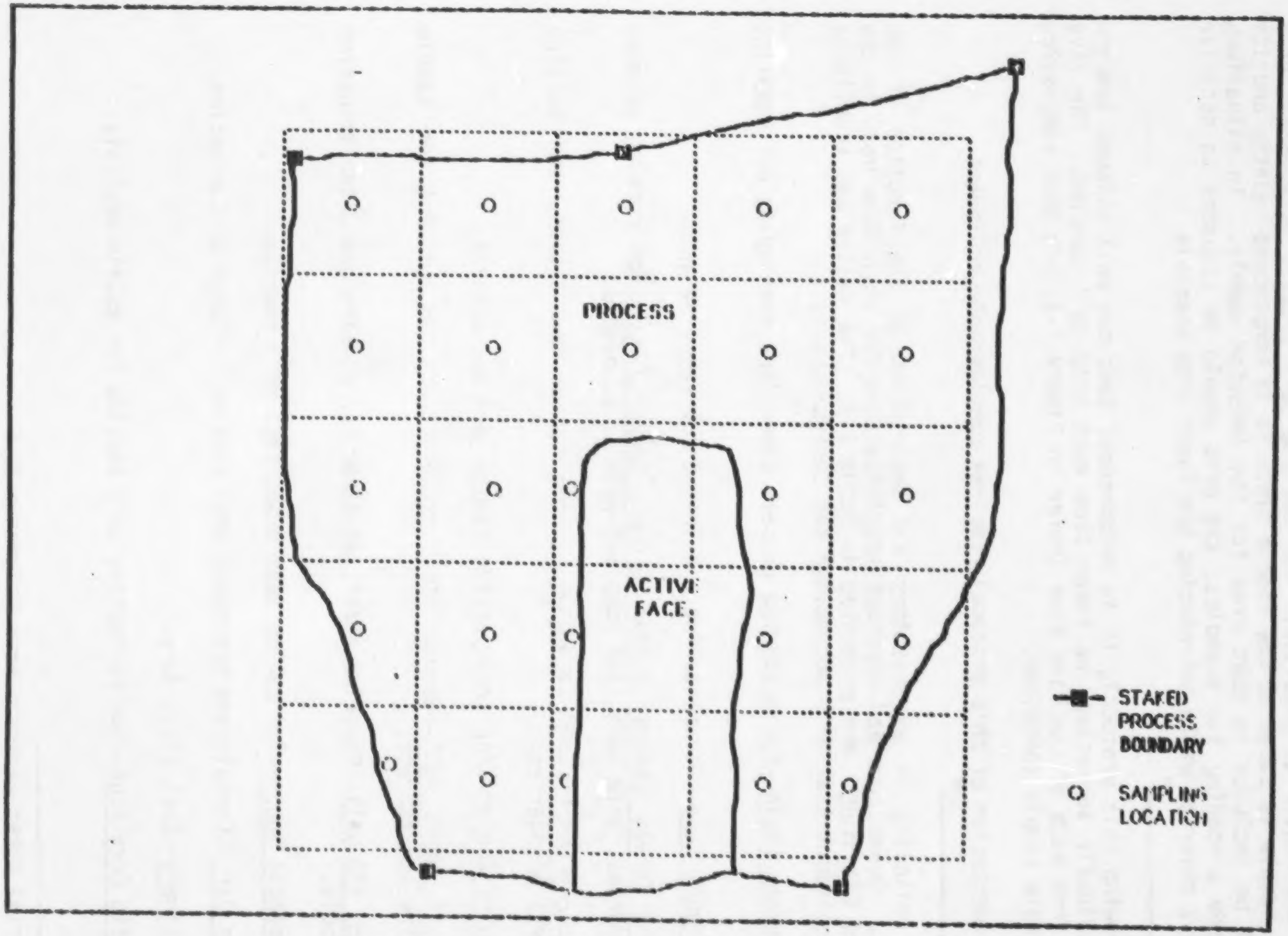
PROCESS
ACTIVE FACE
STAKED PROCESS BOUNDARY
SAMPLING LOCATION

Figure 3-8. Example sketch showing optimal sampling grid location on process and sampling locations resulting from process configuration.

cover any grid cells while still maximizing process coverage. For the cells where the active face covers the center of the cells, the samples are taken as close to the center as possible. For the one cell totally outside the process, the sample is taken at the middle since it is nonprocess related and its area will be included in that used for the emission models. In situations such as the preceding two examples, the grid should be situated to optimize the process coverage while introducing the least bias possible.

*

Following this protocol, it is recommended that one soil aliquot (exceptions previously addressed) be taken from each grid cell sampled. The five aliquots from each of the five rows (refer to Figure 1-1) are then composited into a single sample container.

Implementation of this protocol requires considerable equipment.

*

The following is an inventory and description of the function of the equipment. Quantities and physical specifications for each item used in the referenced EPA study[9] are presented in Table 3-1. The tester may substitute similar equipment that will accomplish the desired goals.

Surveyors Chain--For measuring process dimensions and laying out sampling grids.

Surveyors Tape--For measuring and laying out sampling grid.

Wooden Survey Stakes, Gutter Spikes, Survey Flags--For marking process boundaries, grid axes, and sampling points, as needed.

Plastic Flagging--For flagging gutter spikes and stakes, and marking process boundaries.

40 Quart Cooler--For transporting sample jars and coolant.

Plastic Sheet Roll--Ground cloth on which to set coolers for sample marking and storage.

Carboy (20 gal)--Contains distilled water for rinsing and decontamination of tools.

Disposable Scoop--For taking near subsurface soil samples.

Glass Jars--Contain and transport soil samples, without contamination.

Cap Liners--Seal glass jars.

Plastic Core Tube--For collecting core samples for metals analysis.

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* Material taken directly from Reference 2.

TABLE 3-1. SAMPLING EQUIPMENT SPECIFICATIONS

Description	Dimension*	Material*	Quantity*
Surveyors Chain	200' long, 1/4" wide	Steel	1
Surveyors Tape	100' long, 3/8" wide	Steel	2
Plastic Flagging	1-3/10" x 50 yds	Plastic	1 carton
Wooden Survey Stakes	1" x 2" x 18"	Wood	200
Survey Flags	4" x 5" x 30"	Plastic	100
Gutter Spikes	10" long	Aluminum	50
40 Quart Cooler(s)	Adequate to hold sample jars	Plastic	3
Plastic Sheet Roll	12' x 100' roll	5 mil polyethylene	2
Carboy	20 gallon	Nalgene or glass	1
Disposable Scoops	190 mm long x 118 ml capacity	Styrene	300
Glass Jars	Nominal 475 ml capacity with wide neck	Glass with phenolic cap	300
Cap Liners	To fit glass jars	Teflon	300
Plastic Core Tube	30 cm long x 3.2 cm I.D.	PVC	24
Steel Core Tube	30 cm long x 3.2 cm I.D.	Stainless steel	24
Dowel	40 cm long x 2.5 cm diameter	Wood	48
Surveyors Hammer	5 lb x 18" handle	Steel/wood	1
Wallpaper Paste Brushes	7" handle, 3" bristles, 6" wide	Plastic with nylon bristles	25
Vacuum Sweeper	N/A	With nylon bristle attachment and utilizing disposable paper dust bags	1

(continued)

TABLE 3-1 (continued)

Description	Dimension	Material	Quantity
Shovel	Standard long handle	Steel/wood	1
Pick-ax	Standard long handle	Steel/wood	1
Bucket	12 liter	Stainless steel	1
Bottle Brush	12" long x 1-1/2" diameter	Wire with plastic bristles	2
Plastic Bags	Assorted: 2-quart and 20 gallon	Polyethylene	50 each
Marking Pens	-------------	Permanent ink	20
Log Book	Standard 8-1/2" x 11"	Hard cover	1
Compass	Liquid filled, 5^o increments	Plastic/glass	1

*These are the dimensions, materials of construction, and quantity of equipment used in the referenced EPA study;[9] the tester may substitute similar equipment that will accomplish the desired goals.

Stainless Steel Core Tube--For collecting core samples for organics analysis.

Wooden Dowel--For pressing cored coil from the metal and plastic core tubes.

Surveyors Hammer--For driving core tubes into soil.

Wallpaper Paste Brushes--For sweeping and collecting road dust.

Vacuum Sweeper--For collecting road dust from paved surfaces.

Shovel--For general excavation.

Pick-ax--For general excavation.

Stainless and/or Plastic Steel Bucket--For washing and decontamination of sampling tools.

Bottle Brush--For cleaning and decontaminating core tubes.

Plastic Bags--Contain contaminated equipment prior to decontamination and materials for disposal.

Permanent Marking Pen--For marking sampling scoops/jars.

Bound Log Book--For recording field notes.

Compass--For orienting processes on site plan and laying out process sampling grids.

Site Description Forms--For recording the layout and condition of each process site at the time of sampling.

Chain-of-Custody Forms--For tracing the possession of the samples from origin to analysis.

3.4 WASTE PILES

In sampling the surface of waste piles to determine representative properties for use in the wind erosion equation, a gross sample made up of the top, middle, and bottom incremental samples should ideally be obtained since the wind disturbs the entire surface of the pile. However, it may be impractical to climb waste piles.

The most practical approach in sampling from large piles is to minimize the bias by sampling as near to the middle of the pile as practical and by selecting sampling locations in a random fashion. Incremental samples should be obtained along the entire perimeter of the pile. The spacing between the samples should be such that the entire pile perimeter is traversed with approximately equidistant incremental samples. If small piles are sampled, incremental samples should be collected from the top, middle, and bottom.

An incremental sample (e.g., one shovelful) is collected by skimming the surface of the pile in a direction upward along the face. Every effort must be made by the person obtaining the sample not to purposely avoid sampling larger pieces of raw material. Figure 3-9 presents a data form to be used for the sampling of storage piles.

In obtaining a gross sample for the purpose of characterizing a load-in load-out process, incremental samples should be taken from the portion of the storage pile surface: (1) which has been formed by the addition of aggregate material, or (2) from which aggregate material is being reclaimed.

Type of Material Sampled: ______________________________

Site of Sampling: ______________________________

SAMPLING METHOD

1. Sampling device: pointed shovel
2. Sampling depth: 10 - 15 cm (4 - 6 inches)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every pile sampled
   (b) composite of 10 increments
5. Minimum portion of stored material (at one site) to be sampled: 25%

SAMPLING DATA

Sample No.	Time	Location (Refer to map)	Surface Area	Depth	Quantity of Sample

Figure 3-9. Sampling data form for storage piles.

SECTION 4*

SAMPLE HANDLING AND TRANSPORT

This section describes the specific techniques used to maintain sample integrity.

To avoid contamination, field equipment that will be exposed to sample material should be transported on-site in sealed bags or coolers. Collect scooped samples using disposable, individually wrapped, sterile, nonreactive plastic scoops. Deposit the contents of the scoops directly into sample jars. In the case of cored samples, clean the core tubes before sampling and pack them in sealed plastic bags. Deposit core sample aliquots directly into the sample jars from the core tube. Collect swept samples using a new disposable brush (transported to the site in sealed plastic bags); disposable scoops are used to deposit the swept samples into the glass sample jars. Collect vacuumed samples using a new vacuum sweeper bag transported on-site in a sealed plastic bag. Transfer the contents of the sweeper bag directly into the sample jars.**

In all cases, fill sample jars completely, leaving no head space. Label each sample jar with the facility sampled, date, process description, and sample number, seal with electric tape, and store it in a cooler at a temperature less than 20°C to minimize loss of volatile components. Use a chain-of-custody form for each process. The form should identify each sample and all personnel having custody of the samples at all phases of sample handling. Many agencies will have their own chain-of-custody forms and procedures which should be used by their staff and contractors. An example chain-of-custody form in shown in Figure 4-1.

When all samples have been collected for a particular site, move the sample storage cooler to an uncontaminated area and decontaminate it prior to transport. This decontamination procedure should include washing with soap and water and a final rinse with distilled water.

Samples should be transported from the field in sealed coolers. Surface transportation or air freight can be used to transport the samples for long distances; however, during transport, sample jars must be maintained at temperatures less than 20°C to prevent the evaporation of any volatile components. Pack samples to be shipped by air freight in insulated, impact resistant coolers and cool with "blue-ice," an airline-approved coolant. Make

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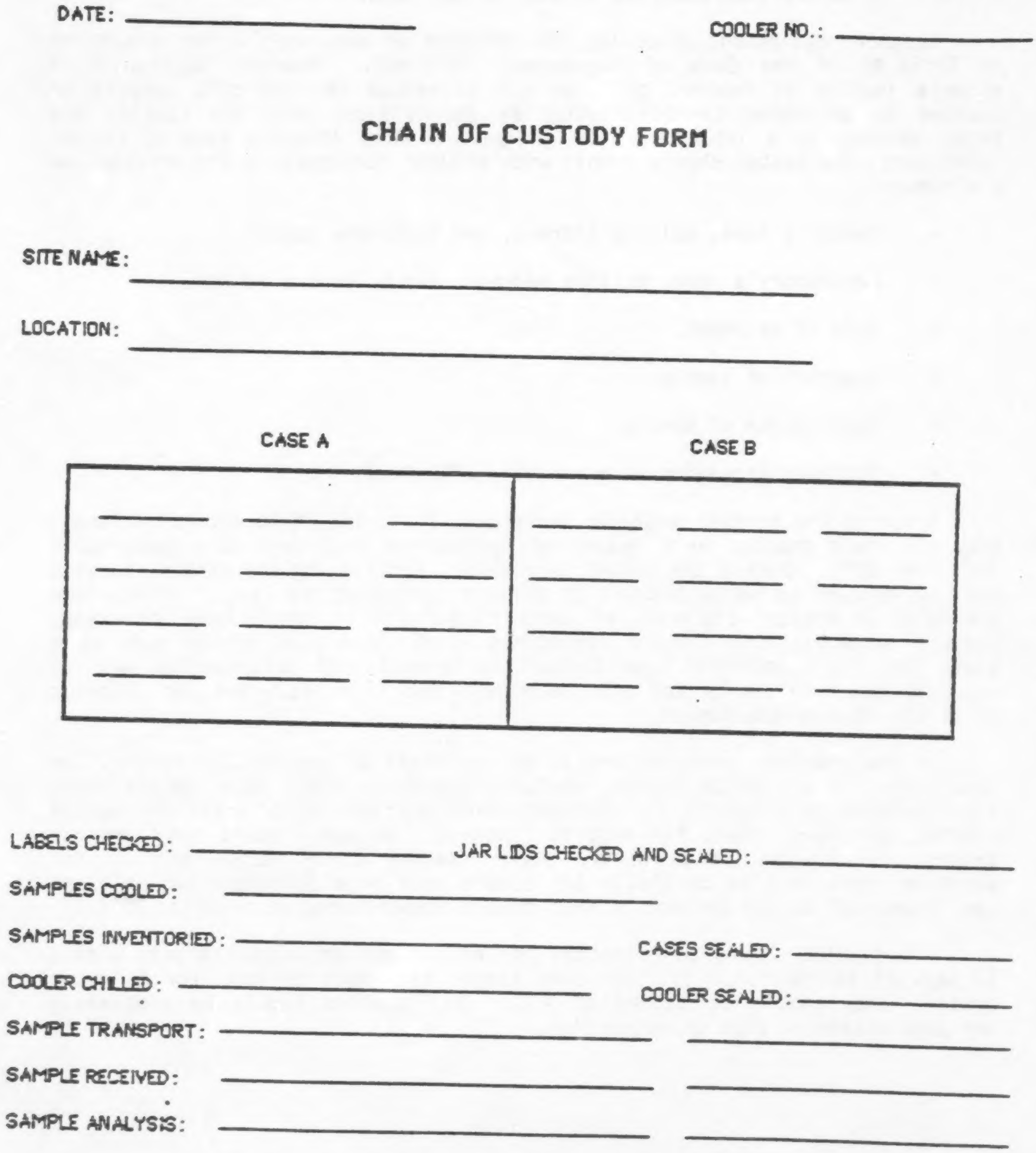
* Material taken directly from Reference 2.

** Disregard this step; leave vacuum bag intact until laboratory analyses.



DATE: ____________________

COOLER NO.: ______________

CHAIN OF CUSTODY FORM

SITE NAME: ______________________________

LOCATION: ______________________________

CASE A			CASE B		

LABELS CHECKED: ______________ JAR LIDS CHECKED AND SEALED: ______________

SAMPLES COOLED: ______________

SAMPLES INVENTORIED: ______________ CASES SEALED: ______________

COOLER CHILLED: ______________ COOLER SEALED: ______________

SAMPLE TRANSPORT: ______________ ______________

SAMPLE RECEIVED: ______________ ______________

SAMPLE ANALYSIS: ______________ ______________

Figure 4-1. Example chain-of-custody form.

arrangements with laboratory personnel so that samples can be picked up and transferred to the laboratory as quickly as possible.

Federal regulations governing the shipment of hazardous wastes are found in Title 40 of the *Code of Regulations*, Part 261. However, Section 261.4 exempts samples of "water, soil, or air collected for the sole purpose of testing to determine characteristics or composition" when the samples are being shipped to a laboratory for analysis. When shipping samples to the laboratory, the tester should comply with shipper requirements and provide, as a minimum:

- Tester's name, mailing address, and telephone number.
- Laboratory's name, mailing address, and telephone number.
- Date of shipment.
- Quantity of sample.
- Description of sample.
- Suitable packaging as previously discussed.

Prior to the initial analyses (moisture, silt, and PM-20 determinations), keep all field samples in a locked refrigerator or cool area at a temperature less than 20°C. During the drying, screening, and sieving operations, samples must be handled using techniques to prevent contamination (e.g., using clean gloves). To prevent dispersal of contaminated soil in sample handling areas, conduct screening and sieving operations within a closed system such as a glove box. All equipment that comes into contact with soil samples must be decontaminated initially and then decontaminated after each use, or disposed of in the appropriate manner.

If the chemical analyses are to be performed by another laboratory, the resulting silt and PM-20 samples should be placed in small amber sample vials for transport or shipment for further analysis. Use 10-mL vials for metals samples and 40-mL vials for organic samples. In cases where they are not shipped or analyzed immediately, store samples at or below 20°C. For shipping, pack samples carefully (in bubble pack in a Styrofoam cooler), and use "blue-ice" as the coolant to keep sample temperatures at or below 20°C.

All samples should be extracted for metals and organics analysis within 14 days of collection. If, for some reason they must be kept for a longer period, they should be stored at 4°C. All samples should be completely analyzed within 40 days of extraction.

SECTION 5

LABORATORY ANALYTICAL METHODS

As indicated in Section A.1, the sampling parameters of concern include:

- Silt content.
- Moisture content.
- Silt loading.
- (α) level of contamination.

The first three parameters represent physical determinations, the latter of course, involves analytical chemistry. The following discusses analytical methods for each of the parameters. Note that there are large differences in sample quantity depending upon whether the sampled source is a waste pile, or unpaved road versus a landfill, land treatment unit, or dry surface impoundment (sampled by the protocol recommended in Reference 2). For convenience, the former is referred to as Case A, the latter as Case B.

5.1 SAMPLE PREPARATION

Sample preparation Case A--once the gross sample is brought to the laboratory, it must be reduced to a workable size. Given that the material may contain unknown levels of contaminant, the most practical procedure for sample reduction probably involves cone and quartering.

The procedure for coning and quartering is best illustrated in Figure 5-1. The following is a description of the procedure: (1) mix the material and shovel it into a neat cone; (2) flatten the cone by pressing the top without further mixing; (3) divide the flat circular pile into equal quarters by cutting or scraping out two diameters at right angles; (4) discard two opposite quarters; (5) thoroughly mix the two remaining quarters, shovel them into a cone, and repeat the quartering and discarding procedures until the sample has been reduced to 0.9 to 1.8 kg (2 to 4 lb). Samples likely to be affected by moisture or drying must be handled rapidly, preferably in an area with a controlled atmosphere, and sealed in a container to prevent further changes during transportation and storage. Care must be taken that the material is not contaminated by anything on the floor or that a portion is not lost through cracks or holes. preferably, the coning and quartering operation should be conducted on a floor covered with clean paper. Coning and quartering is a simple procedure which is applicable to all powdered materials and to sample sizes ranging from a few grams to several hundred pounds.

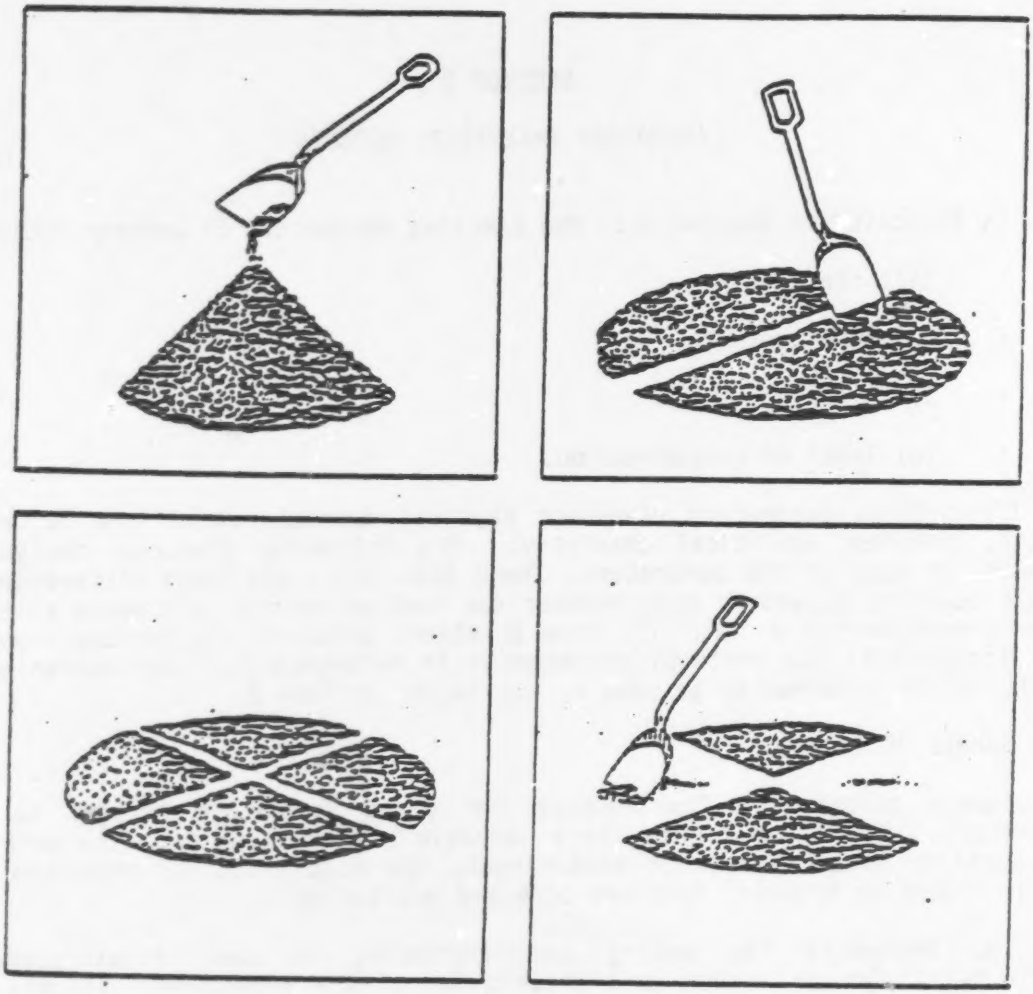


Figure 5-1. Coning and quartering.

The size of the laboratory sample is important--too little sample will not be representative and too much sample will be unwieldy. Ideally, one would like to analyze the entire gross sample in batches, but this is not practical. While all ASTM standards acknowledge this impracticality, they disagree on the exact size, as indicated by the range of recommended samples, extending from 0.05 to 27 kg (0.1 to 60 lb).

The main principle in sizing the laboratory sample is to have sufficient coarse and fine portions to be representative of the material and to allow sufficient mass on each sieve so that the weighing is accurate. A recommended rule of thumb is to have twice as much coarse sample as fine sample. A laboratory sample of 800 to 1,600 g is recommended since that is the largest quantity that can be handled by the scales normally available (1,600-g capacity). Also, more sample than this can produce screen blinding for the 8 in diameter screens normally available. Note that it may be more practical to perform sample reduction (i.e., cone and quartering) prior to shipping the sample back to the laboratory.

Sample preparation Case B--under the sampling protocol, it is assumed that sampling procedures yield five samples (in separate sample jars). These individual samples are subjected to physical analyses and then ultimately combined into a single silt composite. The flowchart for the various analyses is shown in Figure 5-2.

5.2 SILT CONTENT

The basic recommended procedure for silt analysis is mechanical, dry sieving after moisture analysis (see 5.3 below). A step-by-step procedure is given in Table 5-1. The sample should be oven-dried for 24 h at 230°F before sieving. The sieving time is variable; sieving should be continued until the net sample weight collected in the pan increases by less than 3.0% of the previous net sample weight collected in the pan. A minor variation of 3.0% is allowed since some sample grinding due to interparticle abrasion will occur, and consequently, the weight will continue to increase. When the change reduces to 3.0%, it is felt that the natural silt has been passed through the No. 200 sieve screen and that any additional increase is due to grinding. An example silt analysis form is given in Figure 5-3.

5.3 MOISTURE CONTENT

For moisture content determinations, MRI has typically recommended the procedure given in Table 5-2. An example recording form is given as Figure 5-4.

The protocol given in Reference 2 recommends a somewhat different set of procedures. These procedures are given below.

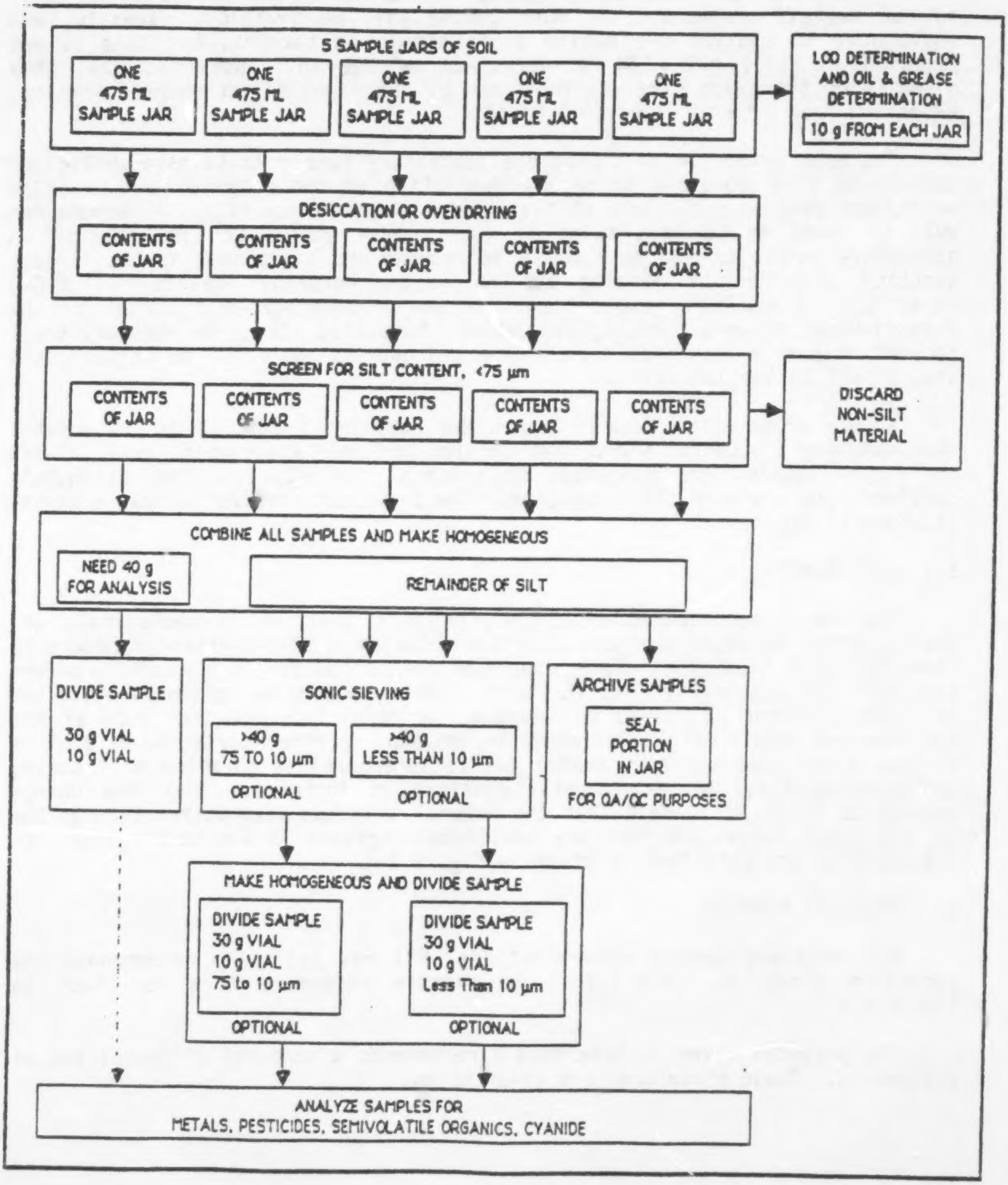

5 SAMPLE JARS OF SOIL
ONE 475 ML SAMPLE JAR
ONE 475 ML SAMPLE JAR
ONE 475 ML SAMPLE JAR
ONE 475 ML SAMPLE JAR
ONE 475 ML SAMPLE JAR
LOD DETERMINATION AND OIL & GREASE DETERMINATION
10 g FROM EACH JAR
DESICCATION OR OVEN DRYING
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
SCREEN FOR SILT CONTENT, <75 µm
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
CONTENTS OF JAR
DISCARD NON-SILT MATERIAL
COMBINE ALL SAMPLES AND MAKE HOMOGENEOUS
NEED 40 g FOR ANALYSIS
REMAINDER OF SILT
DIVIDE SAMPLE
30 g VIAL
10 g VIAL
SONIC SIEVING
>40 g 75 TO 10 µm
OPTIONAL
>40 g LESS THAN 10 µm
OPTIONAL
ARCHIVE SAMPLES
SEAL PORTION IN JAR
FOR QA/QC PURPOSES
MAKE HOMOGENEOUS AND DIVIDE SAMPLE
DIVIDE SAMPLE
30 g VIAL
10 g VIAL
75 to 10 µm
OPTIONAL
DIVIDE SAMPLE
30 g VIAL
10 g VIAL
Less Than 10 µm
OPTIONAL
ANALYZE SAMPLES FOR
METALS, PESTICIDES, SEMIVOLATILE ORGANICS, CYANIDE

Figure 5-2. Flow diagram for samples taken from a process.

TABLE 5-1. SILT ANALYSIS PROCEDURES

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in., No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particulate sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as vibratory shaker or a Roto-Tap.

3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.

4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy (if available).

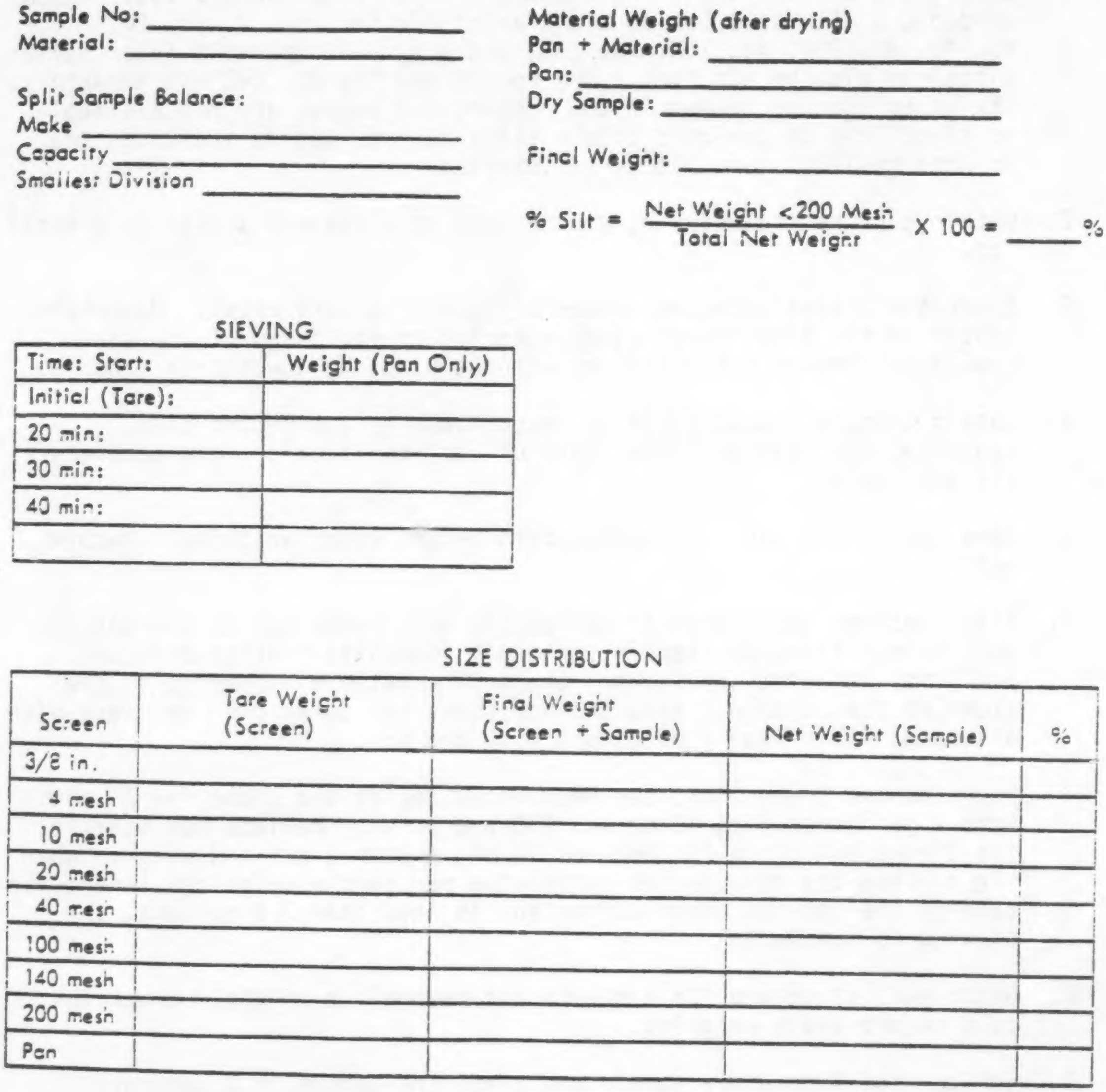
5. Tare sieves and pan. Check the zero before every weighing. Record weights.

6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device and sieve for 20 min. Remove pan containing minus No. 200 and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the differences between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0 percent, the sieving is complete.

8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.

9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.



Sample No: ____________________

Material: ____________________

Split Sample Balance:

Make ____________________

Capacity ____________________

Smallest Division ____________________

Material Weight (after drying)

Pan + Material: ____________________

Pan: ____________________

Dry Sample: ____________________

Final Weight: ____________________

$$\% \text{ Silt} = \frac{\text{Net Weight} < 200 \text{ Mesh}}{\text{Total Net Weight}} \times 100 = \_\_\_\_ \%$$

SIEVING

Time: Start:	Weight (Pan Only)
Initial (Tare):	
20 min:	
30 min:	
40 min:	

SIZE DISTRIBUTION

Screen	Tare Weight (Screen)	Final Weight (Screen + Sample)	Net Weight (Sample)	%
3/8 in.				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Figure 5-3. Example silt analysis form.

TABLE 5-2. MOISTURE ANALYSIS PROCEDURE

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.

2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.

3. Record the make, capacity, smallest division, and accuracy of the scale.

4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.

5. Place sample in oven and dry overnight.[a]

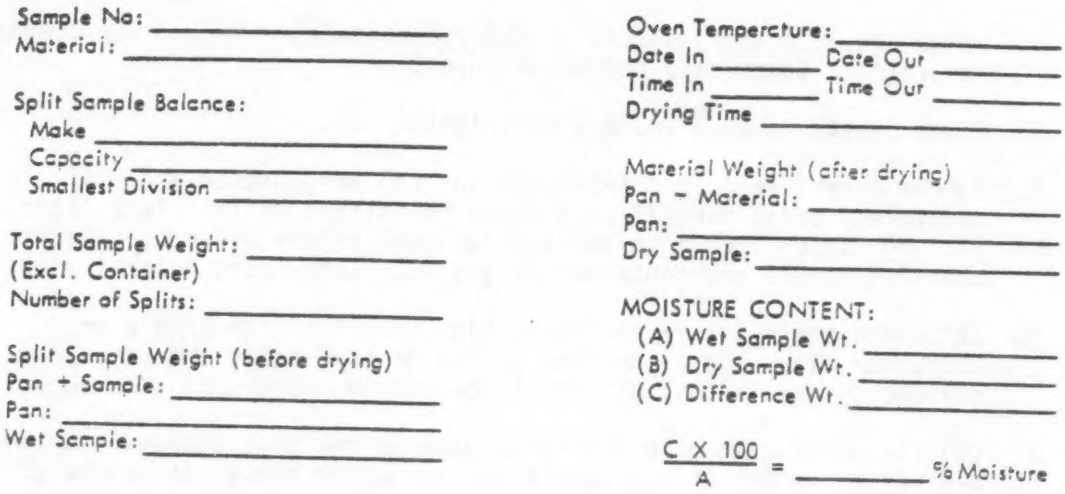
6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.

7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.

8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

---

[a] Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 h. Because of this short drying time, material dried for only 1-1/2 h must not be more than 2.5 cm (1 in.) deep in the container.



Sample No: ____________
Material: ____________

Split Sample Balance:
Make ____________
Capacity ____________
Smallest Division ____________

Total Sample Weight: ____________
(Excl. Container)
Number of Splits: ____________

Split Sample Weight (before drying)
Pan + Sample: ____________
Pan: ____________
Wet Sample: ____________

Oven Temperature: ____________
Date In ________ Date Out ________
Time In ________ Time Out ________
Drying Time ____________

Material Weight (after drying)
Pan + Material: ____________
Pan: ____________
Dry Sample: ____________

MOISTURE CONTENT:
(A) Wet Sample Wt. ____________
(B) Dry Sample Wt. ____________
(C) Difference Wt. ____________

$\frac{C \times 100}{A}$ = ________ % Moisture

Figure 5-4. Example moisture analysis form.

5.3.1 Loss-on-Drying (LOD) Determination*

ASTM Method D2216-71 ("Laboratory Determination of Moisture Content of Soils") is used to provide an indirect measure of the moisture content of each soil sample. A data sheet similar to the one shown in Figure 5-5 is used to record the LOD data.

For the LOD determination, analytically weigh approximately 10 g of the "raw" soil sample from each sample jar into a tared, 5-cm-diameter glass jar with a tight fitting lid. If there is standing water in the jar, it should not be sampled for the LOD determination. Remove the jar lids and dry the samples overnight (12 to 16 h) in an oven at 105°C. Remove the LOD samples from the oven and place them in a desiccator to cool; remove the cooled samples from the desiccator and replace the jar lids. Reweigh each dried LOD sample and determine the percent LOD using the following formula:

$$\% \text{ LOD} = \frac{\text{jar and sample wet wt.} - \text{jar and sample dry wt.}}{\text{sample wet wt.}} \times 100\%$$

5.3.2 Oil and Grease Content Determination**

Analyze any land treatment samples for oil and grease content according to Method 503 D in "Standard Methods for the Examination of Water and Wastewater."[7] The method involves extraction of 10 g of "raw" sample with 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) followed by gravimetric determination of the dried extract.

5.3.3 Sample Drying Procedure***

Dry the contents of each sample jar taken from a process using one of the two procedures described below, depending on the average percent LOD measured for that process. If the LOD is less than 10%, desiccate the five sample portions over anhydrous calcium sulfate until they show no more than 1% weight loss upon further drying. If the measured LOD is greater than 10%, dry the five sample portions in an oven at 105°C until they show no more than 1% weight loss upon further drying. A data sheet similar to the one shown in Figure 5-6 is used to record and calculate the actual sample weight loss during desiccation or drying.

In the desiccation procedure, clean the desiccator by washing the interior with water which conforms to the specifications for ASTM, Type 3 water (referred to herein as D.I. water).[8] Follow this with an acetone rinse and a final methylene chloride rinse. Spread a 1-in layer of anhydrous calcium sulfate over the bottom of the desiccator. Split the contents of each sample jar (approximately 1 kg) between two tared, 9-in Pyrex pie plates that have been previously cleaned with D.I. water, acetone, and methylene

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* Material taken directly from Reference 2.
** Material taken directly from Reference 2.
*** Material taken directly from Reference 2.

LOSS-ON-DRYING (LOD) DETERMINATION DATA SHEET

Site ______________________________

Process ______________________________

Analyst ____________________ Date __________

Reviewed by ____________________ Date __________

Sample Jar Number					
Jar Tare Wt. (g)					
Jar and Sample Wet Wt. (g)					
Sample Wet Wt. (g)					

Sample Wet Wt. = Jar and Sample Wet Wt. - Jar Tare Wt.

Oven Temperature(^{o}C)					
Time In Oven					
Time Out Oven					
Total Drying Time					
Jar and Sample Dry Wt. (g)					
% LOD					

$$\% \text{ LOD} = \frac{\text{Jar and Sample Wet Wt.} - \text{Jar and Sample Dry Wt.}}{\text{Sample Wet Wt.}} \times 100\%$$

Figure 5-5. Loss-on-drying (LOD) determination data sheet.

SAMPLE DRYING WEIGHT LOSS DATA SHEET

Oven ________
Desiccation ________

Site ____________________ Analyst ____________ Date ________
Process ____________________ Reviewer ____________ Date ________

Sample Jar Number ________ Pan Tare Weights ______ + ______ = ________

Time Sample Pan Weights Sample Weight

______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________

Sample Jar Number ________ Pan Tare Weights ______ + ______ = ________

Time Sample Pan Weights Sample Weight

______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________

Sample Jar Number ________ Pan Tare Weights ______ + ______ = ________

Time Sample Pan Weights Sample Weight

______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________
______ ______ + ______ = ______ - Pan Tare Wts. = __________

$$\text{Percent Weight Loss} = \frac{\text{Sample Wet Wt.} - \text{Sample Dry Wt.}}{\text{Sample Wet Wt.}} \times 100\%$$

% WEIGHT LOSS AT TIME INTERVAL

Sample Jar Number					
Time ______					
Time ______					
Time ______					
Time ______					

Figure 5-6. Sample drying weight loss data sheet.

chloride. Determine each pie plate tare weight and the weight of each pie plate with its wet sample contents. Place sample in the desiccator and desiccate until it shows no more than 1% weight loss on further desiccation. Determine the weight of each pie plate with the sample portion when dry and calculate the percent loss-on-desiccation using the following formula:

$$\% \text{ weight loss} = \frac{\text{sample wet wt.} - \text{sample dry wt.}}{\text{sample wet wt.}} \times 100\%$$

For oven-drying, first wipe the oven interior clean with D.I. water, followed by acetone and methylene chloride. Split the contents of each sample jar between two clean, tared pie plates. Determine each pie plate tare weight and the weight of each pie plate with its wet sample contents. Set the oven temperature at 105°C. Place sample in the oven and dry until it shows no more than 1% weight loss on further drying (dry enough to be sieved); remove to a clean desiccator to cool. Determine the dry weight of the sample and calculate the percent loss-on-drying using the formula above.

Return the desiccated or oven-dried samples to clean, dry sample jars and store at or below 20°C,* or keep the samples in the desiccator and sieve the same day.

5.4 SILT LOADING

5.4.1 Sample Preparation and Analysis for Total Loading

The gross sample of paved road dust will arrive at the laboratory in two types of containers: (1) the broom-swept dust will be in sample containers; and (2) the vacuum-swept dust will be in vacuum bags.

Both the broom-swept dust and the vacuum-swept dust are weighed on a beam balance. The broom-swept dust is weighed in a tared container. The vacuum-swept dust is weighed in the vacuum bag which was tared and equilibrated in the laboratory before going to the field. The vacuum bag and its contents should be equilibrated again in the laboratory before weighing.

The total surface dust loading on the traveled lanes of the paved road is then calculated in units of kilograms of dust on the traveled lanes per kilometer of road. When only one strip of length is taken across the traveled lanes, the total dust loading on the traveled lanes is calculated as follows:

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* If not extracted within 14 d after collection, the samples must be stored at 4°C.

$$L = \frac{m_b + m_v}{\ell}$$

where: m_b = mass of the broom-swept dust, kg

m_v = mass of the vacuum-swept dust, kg

ℓ = length of strip as measured along the centerline of the road, km

When several incremental samples are collected on alternate roadway halves, the total surface dust loading is calculated as follows:

$$L = \frac{m_{b1} + m_{v1} + m_{b5} + m_{v5}}{\ell_1 + \ell_5} +$$

$$\frac{m_{b2} + m_{v2} + m_{b6} + m_{v6}}{\ell_2 + \ell_6} +$$

$$\frac{m_{b3} + m_{v3} + m_{b5} + m_{v7}}{\ell_3 + \ell_7} +$$

$$\frac{m_{b4} + m_{v4} + m_{b8} + m_{v8}}{\ell_4 + \ell_8} +$$

where: m_{b_i} = mass of broom sweepings for increment i, kg

m_{v_i} = mass of vacuum sweepings for increment i, kg

ℓ = length of increment i is measured along the road centerline, km

5.4.2 Sample Preparation and Analyses for Road Dust Silt Content

After weighing the sample to calculate total surface dust loading on the traveled lanes, the broom-swept and vacuum-swept dust is composited. The composited sample is usually small and requires no sample splitting in preparation for sieving. If splitting is necessary to prepare a laboratory sample of 800 to 1,600 g, the cone and quartering technique discussed in Section 5.1 can be used. The laboratory sample is then sieved using the techniques described in Section 5.2.

5.4.3 Sample Packing

If any of the samples are sent to another laboratory for chemical analysis, pack in amber vials (40-mL with Teflon-lined septa and phenolic caps). Before use, clean and rinse the vials sequentially with dilute nitric acid, D.I. water, acetone, and pesticide-grade methylene chloride. Package into the vials 30 g of a sample for organic analysis and 10 g of a sample for metals analysis. Label the vials as shown in Figure 5-7.

Sample No. AW-10-2 Date: 03/18/86
Description: 30 g Silt Composite
Process: Landfill Cell 10
Site: Acme Waste Disposal Co.

Figure 5-7. Sample label.

SECTION 6*

CHEMICAL ANALYSES

6.1 METALS ANALYSIS

For analysis of the metals of interest listed in Table 6-1, the methods used are from the EPA publication, "Testing Methods for Evaluating Solid Waste," SW-846. Prepare samples for analysis of all metals except mercury (Hg) by acid digestion using EPA Method 3050 (SW-846). Prepare and analyze the mercury sample by the cold vapor atomic absorption procedure following EPA Method 7471 (SW-846). Use the following two modifications in the final dilutions of the digested samples. Dilute the samples for ICAP determination by EPA Method 6010 (SW-846) and furnace atomic absorption determination of antimony (Sb) by EPA Method 7041 (SW-846) to achieve a final concentration of 5% hydrochloric acid. Dilute the digested samples for arsenic (As) determination by EPA Method 7060 (SW-846), for selenium (Se) determination by EPA Method 7740 (SW-846), and for thallium (Tl) determination by EPA Method 7841 (SW-846) to achieve a final concentration of 0.5% nitric acid.

For chromium, the analysis described above, using EPA Method 6010[6] and ICAP, should serve as a screening technique. If the results for any sample show a relatively significant concentration of chromium, then another aliquot of that sample should be analyzed for hexavalent chromium (Cr VI) which is much more toxic than the other forms. This further analysis is conducted using EPA Method 3060 (alkaline extraction) in combination with EPA Method 7195 (coprecipitation/AA), 7196 (colorimetric), or 7197 (chelation/AA).

6.2 CYANIDE ANALYSIS

Cyanide determinations are performed by colorimetric measurement following EPA Method 335.2 found in "Methods for the Evaluation of Water and Wastewater.[7] The method involves distillation of the cyanide, as hydrocyanic acid, into a sodium hydroxide absorbing solution. The cyanide ion in the absorbing solution is determined colorimetrically.

6.3 SEMIVOLATILE ORGANIC ANALYSIS

For the semivolatile organic analysis, prepare the samples by sonication extraction (Method 3550, SW-846) using the procedures specified in the CLP Statement of Work for Organic Analysis. Prepare the extracts at the low concentration level using 30 g of sample and subject them to adsorption

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* Material taken directly from Reference 2.

TABLE 6-1. METALS AND MEASUREMENT METHODS

Element	Measurement Method**
Aluminum (Al)	ICAP
Antimony (Sb)	GFAA
Arsenic* (As)	GFAA
Barium* (Ba)	ICAP
Beryllium (Be)	ICAP
Bismuth (Bi)	ICAP
Cadmium* (Cd)	ICAP
Chromium* (Cr)	ICAP⁺
Cobalt (Co)	ICAP
Copper (Cu)	ICAP
Iron (Fe)	ICAP
Lead* (Pb)	ICAP
Manganese (Mn)	ICAP
Mercury* (Hg)	Cold Vapor AA
Molybdenum (Mo)	ICAP
Nickel (Ni)	ICAP
Osmium (Os)	ICAP
Selenium* (Se)	GFAA
Silver* (Ag)	ICAP
Thallium (Tl)	GFAA
Vanadium (V)	ICAP
Zinc (Zn)	ICAP

*Eight RCRA metals

**ICAP = Inductively-Coupled Argon Plasmography
GFAA = Graphite Furnace Atomic Absorption
AA = Atomic Absorption

⁺Other methods are used to measure hexavalent chromium (Cr IV), if appropriate (see page E-43 for discussion).

chromatography on Sephadex LH-20. Concentrate the extracts and determine their weight. Take approximately 200 mg of each concentrated extract, weigh accurately, and redissolve in 2 mL of a 1:1 mixture of methylene chloride and methanol. Calculate the dilution factor for the LH-20 procedure using the following formula:

$$\text{LH-20 dilution factor} = \frac{\text{weight of concentrated extract (mg)}}{\text{exact weight of 200-mg portion}}$$

Calibrate and monitor the LH-20 system according to the procedure in the CLP for the gel permeation chromatography system. For the LH-20 procedure, use an eluent solvent system consisting of a 1:1 mixture of methylene chloride and methanol. Load the 200-mg redissolved sample extract directly onto the column. Adjust the eluent flow rate to 100 mL/h. Collect the proper fraction containing the aromatic compounds, and concentrate the fraction to 1 mL.

Analyze the extract according to the CLP procedure: screen them by gas chromatography with a flame ionization detector (GC/FID) to determine the proper dilution level. Minimize the amount of dilution to maintain the detection level at as low a level as possible. Use a capillary column gas chromatograph/mass spectrometer (GC/MS) to analyze for the organic compounds listed in Table 6-2 which were derived from the Hazardous Substances List (HSL) in the CLP. Use the internal standard calibration method in the CLP to quantify the HSL compounds found in the extracts.

Samples particularly high in oil and grease (such as those obtained from land treatment processes) may require additional cleanup or other treatment for analysis. Additional cleanup can be achieved by repeating the LH-20 procedure. Each time the cleanup procedure is repeated, the sample(s) should be rescreened by GC/FID to determine if the additional cleanup is continuing to make progress. Following each cleanup, use the quality control guidelines described in the CLP for surrogate recovery to ensure that excessive loss of aromatic compounds does not occur. In some instances, even repeated cleanup will not yield samples which can be analyzed at the low concentration level. In these instances the analyst may analyze them at the medium concentration level and/or may consider alternative analytical techniques. These techniques may include the methods from EPA SW-846 which utilize other cleanup procedures with GC techniques and which are only specific for certain groups of compounds.

6.4 PESTICIDES ANALYSIS

For samples selected for pesticides analysis, follow the CLP procedures for pesticides and PCBs. For this analysis, use a portion of the sample's semivolatile organic extract and subject the extract to solvent exchange. Analyze the solvent-exchanged extract for the pesticides and PCBs (Aroclor's) listed in Table 6-3 using gas chromatography/electron capture detection (GC/ECD).

TABLE 6-2. SEMIVOLATILE ORGANIC COMPOUNDS FOR ANALYSIS

ACENAPHTHENE
ACENAPHTHYLENE
ANTHRACENE
BENZO (a) ANTHRACENE
BENZOIC ACID
BENZO (a) PYRENE
BENZO (ghi) PERYLENE
BENZO (b) FLUORANTHENE
BENZO (k) FLUORANTHENE
BENZYL ALCOHOL
BIS (2-CHLOROETHOXY) METHANE
BIS (2-CHLOROETHYL) ETHER
BIS (2-CHLOROISOPROPYL) ETHER
BIS (2-ETHYHEXYL) PHTHALATE
4-BROMOPHENYL PHENYL ETHER
BUTYL BENZYL PHTHALATE
4-CHLOROANILINE
4-CHLORO-3-METHYLPHENOL
2-CHLORONAPHTHALENE
2-CHLOROPHENOL
4-CHLOROPHENYL PHENYL ETHER
CHRYSENE
DIBENZO (a.h) ANTHRACENE
DIBENZOFURAN
1.2 DICHLOROBENZENE
1.3 DICHLOROBENZENE
1.4 DICHLOROBENZENE
3.3'-DICHLOROBENZIDINE
2.4-DICHLOROPHENOL
DIETHYLPHTHALATE
2.4-DIMETHYLPHENOL
DIMETHYL PHTHALATE
DI-N-BUTYLPHTHALATE
2.4-DINITROPHENOL
2.4-DINITROTOLUENE
2.6-DINITROTOLUENE
DI-N-OCTYL PHTHALATE
FLUORANTHENE
FLUORENE
HEXACHLOROBENZENE
HEXACHLOROBUTADIENE
HEXACHLOROCYCLOPENTADIENE
HEXACHLOROETHANE
INDENO(1.2.3-cd) PYRENE
ISOPHORONE
2-METHYL-4.6-DINITROPHENOL
2-METHYLNAPHTHALENE
2-METHYLPHENOL
4-METHYLPHENOL
NAPHTHALENE
2-NITROANILINE
3-NITROANILINE
4-NITROANILINE
NITROBENZENE
2-NITROPHENOL
4-NITROPHENOL
N-NITROSO-DI-N-PROPYLAMINE
N-NITROSODIPHENYLAMINE
PENTACHLOROPHENOL
PHENANTHRENE
PHENOL
PYRENE
1.2.4-TRICHLOROBENZENE
2.4.5-TRICHLOROPHENOL
2.4.6-TRICHLOROPHENOL

TABLE 6-3. PESTICIDES FOR ANALYSIS

ALDRIN
Alpha - BHC
Beta - BHC
Delta - BHC
Gamma - BHC
CHLORDANE
4,4'-DDD
4,4'-DDE
4,4'-DDT
DIELDRIN
ENDOSULFAN I
ENDOSULFAN II
ENDOSULFAN SULFATE
ENDRIN
ENDRIN KETONE
HEPTACHLOR
HEPTACHLOR EPOXIDE
TOXAPHENE
AROCLOR 1016
AROCLOR 1221
AROCLOR 1232
AROCLOR 1242
AROCLOR 1248
AROCLOR 1254
AROCLOR 1260

SECTION 7*

QUALITY ASSURANCE PROCEDURES

The quality assurance (QA)/quality control (QC) procedures described in this section provide a performance audit, quality control, duplicate analyses, and independent analyses. The quality control procedures for providing corrective action are the internal quality control procedures instituted by each individual laboratory.

The internal QC procedures instituted by each laboratory should involve the use of known QC samples, spiked samples, duplicate samples, matrix-spiked samples, duplicate matrix-spiked samples, surrogate-spiked samples, and method blanks.

For the metals analysis, use National Bureau of Standards (NBS) water (1643 B) as check samples for the accuracy of the instrumentation. Use a marine sediment reference material (MESS-1)** and an NBS fly ash sample (1633 A)*** as QC samples to check the overall accuracy of the digestion and analysis procedures. Spike one process sample with the eight elements listed in Table 7-1, and calculate their percent recoveries to assess matrix effects. Prepare and analyze another sample in duplicate to demonstrate analytical precision.

For the QC on the analysis of the semivolatile organics and pesticides, follow the procedures in the Contract Laboratory Program (CLP) protocol. Use an extra 60 g of a sample for a matrix spike (MS) and a matrix spike duplicate (MSD). Determine the percent recoveries and calculate the relative percent difference (RPD) for the duplicates. Compare the results for the MS and MSD with the acceptable percent recovery range and the RPD specified in the CLP protocol. Spike all samples prior to extraction with surrogate compounds and determine the percent recoveries of these compounds. Recovery of less than 10% of any one surrogate or recovery of two or more surrogates outside the recovery limits stated in the CLP require that the sample extract be reanalyzed. If the recovery is outside the limits upon reanalysis, then the sample must be reextracted and reanalyzed.

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* Material taken directly from Reference 2.

** Available from Marine Analytical Chemistry Standards Program of the Canadian National Research Division of Chemistry, Montreal Road, Ottawa, Canada, K1A 0R9.

*** Available from the National Bureau of Standards, Office of Standard Reference Materials, Room B-311, Chemistry Building, Washington, DC 20234.

TABLE 7-1. SPIKING COMPOUNDS: METALS

Solvent: 0.5% Nitric Acid

Compound	Concentration (μg/ml)
Arsenic (As)	100
Barium (Ba)	100
Beryllium (Be)	100
Cadmium (Cd)	100
Calcium (Ca)	100
Copper (Cu)	100
Lead (Pb)	100
Magnesium (Mg)	100
Manganese (Mn)	100
Selenium (Se)	100
Silver (Ag)	100
Zinc (Zn)	100

Analyze two blank samples consisting of a purified solid matrix spiked with surrogate compounds and carried through extraction and concentration. One blank is for the samples and the other blank is for the MS and MSD. Compare the results with both the CLP-specified surrogate recovery limits for the blanks and with the CLP limits on the levels of common phthalate esters and Hazardous Substances List (HSL) compounds.

Conduct a performance audit to assess the precision and accuracy of the laboratory analyses. This audit should be conducted only once during the entire testing program at a TSDF. From a homogeneous composite sample, remove three 30-g aliquots for an organics analysis audit and three 4-g aliquots for a metals analysis audit. Spike one of the 30-g aliquots with the EPA reference materials whose contents are listed in Tables 7-2 through 7-4, and if applicable, Table 7-5. The amount of spiking material should be at least 10 times the anticipated detection limit in a 30-g sample. Spike one of the 4-g aliquots with the elements listed in Table 7-1. Use a multielement atomic absorption standard. The amount of material to be added to a 4-g sample should yield a concentration 10 times the anticipated detection limit for the metals analysis.

Have the laboratory analyze the spiked sample and two of the unspiked samples. Replicate analysis of the spiked sample is recommended. The duplicate unspiked samples analyzed by the laboratories give a measure of precision. Use the mean of the duplicate analysis to correct the spiked sample results for corresponding compounds present in the unspiked sample. Compare the corrected results of the spiked sample to the true value to determine the accuracy of the analysis.

TABLE 7-2. SPIKING COMPOUNDS: ACID EXTRACTABLES II

Standard Code: C-090-01 Solvent: CH_2Cl_2

Compound	Concentration* (µg/ml)
Benzoic acid	2000
p-Chloro-m-cresol	2000
2-Chlorophenol	2000
o-Cresol	2000
p-Cresol	2000
2,4-Dichlorophenol	2000
2,4-Dimethylphenol	2000
4,6-Dinitro-o-cresol	2000
2,4-Dinitrophenol	2000
2-Nitrophenol	2000
4-Nitrophenol	2000
Pentachlorophenol	2000
Phenol	2000
2,4,5-Trichlorophenol	2000
2,4,6-Trichlorophenol	2000

TABLE 7-3. SPIKING COMPOUNDS: NEUTRAL EXTRACTABLES V

Standard Code: C-040

Solvent: CH_2Cl_2

Compound	Purity (%)	Concentration (ug/ml)
Acenaphthene	98+	2000
Anthracene	99+	2000
Benzo(k)fluoranthene	99+	2000
Dibenz(a,h)anthracene	99+	2000
Dibenzofuran	99+	2000
1,2-Dichlorobenzene	99+	2000
1,4-Dichlorobenzene	99+	2000
bis(2-Ethylhexyl)phthalate	99+	2000
Fluorene	99+	2000
Hexachlorobenzene	99+	2000
Hexachlorocyclopentadiene	99+	2000
Isophorone	99+	2000
Nitrobenzene	99+	2000
N-Nitrosodi-n-propylamine	99+	2000
Pyrene	99+	2000

TABLE 7-4. SPIKING COMPOUNDS: NEUTRAL EXTRACTABLES VI

Standard Code: C-041

Solvent: CH_2Cl_2

Compound	Purity (%)	Concentration (µg/ml)
Benzo(a)pyrene	98+	2000
Benzo(g,h,i)perylene	99+	2000
Benzyl alcohol	99+	2000
4-Bromophenyl phenyl ether	99+	2000
bis(2-Chloroethyl)ether	99+	2000
2-Chloronaphthalene	99+	2000
4-Chlorophenyl phenyl ether	99+	2000
Chrysene	99+	2000
Diethyl phthalate	99+	2000
Dimethyl phthalate	99+	2000
Di-n-butyl phthalate	99+	2000
Di-n-octyl phthalate	99+	2000
Hexachlorobutadiene	99+	2000
Hexachloroethane	99+	2000
Naphthalene	99+	2000

TABLE 7-5. SPIKING COMPOUNDS: PESTICIDES II

Standard Code: C-093-01 Solvent: Toluene/Hexane (1:1)

Compound	Concentration* (μg/ml)
Aldrin	2000
Alpha-BHC	2000
Beta-BHC	2000
Delta-BHC	2000
Gamma-BHC	2000
4,4'-DDD	2000
4,4'-DDE	2000
4,4'-DDT	2000
Dieldrin	2000
Endosulfan II	2000
Endosulfan II	2000
Endosulfan sulfate	2000
Endrin	2000
Endrin aldehyde	2000
Heptachlor	2000
Heptachlor epoxide	2000
Endrin ketone	1000
p,p'-Methoxychlor	2000

*Concentration corrected for purity.

REFERENCES TO APPENDIX D

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3. Cochran, W. G. "Sampling Techniques." John Wiley and Sons, New York, New York. 413 pp. 1965.

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8. "ASTM D 1193-74, Standard Specifications for Reagent Water."

9. "Assessment of Hazardous Waste TSDF Particulate Emissions." Draft Final Report by MRI prepared for the U.S. Environmental Protection Agency under Contract No. 68-02-3891, Work Assignment No. 5. May 5, 1986.